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Monitoring for success in stream restoration: a case study of the Kama Creek, north shore of Lake Superior

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MONITORING FOR SUCCESS IN STREAM RESTORATION: A CASE STUDY OF THE KAMA CREEK, NORTH SHORE OF LAKE SUPERIOR

By

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ABSTRACT

This thesis investigates the use of success criteria to evaluate the changes induced by a small-scale stream restoration project. The research is based on a case study of the Kama Creek, Nipigon Bay, Lake Superior. Declines in coaster brook trout in the creek due to the realignment of the stream channel led to the need for restoration of the creek and its floodplain to its original configuration. The need for efficient post-project evaluation, particularly for small-scale projects, is evident and protecting Coaster brook trout (*Savelinus fontinalis)* habitat and spawning locations in the Lake Superior region is of considerable importance for fisheries management.

Chemical, biological and physical assessments were completed on Kama Creek before and after restoration in order to evaluate ecological health and channel stability of the stream. Success criteria chosen were based on the requirements for the health of brook trout and the overall function and stability of the stream.

Findings show that the restoration project has improved stream condition and habitat availability when compared to the pre-restoration conditions. The results showed an increase in the area of large pools and an accompanying increase in fish observed in the newly restored channel and in regions of the watershed once restricted by an impasse. There were exceptions to this success in regards to bank stabilization and sediment deposition, and future monitoring will be required to evaluate if conditions stabilize regardless of discharge and extreme rainfall, and to determine if human intervention is needed.

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CHAPTER 1

INTRODUCTION

Stream restoration projects have become increasingly common, and the need for efficient post-project evaluation, particularly for small-scale projects, is evident. (Bernhardt et al., 2005; Henry et al., 2002; Palmer et al. 2014; Purcell et al. 2002 and Roni, 2005). The need for systematic post-project evaluation is now evident at all scales, but particularly for small-scale projects that do not receive adequate baseline data collection and post-restoration monitoring (Purcell et al., 2002).

Many stream restoration projects do not include a requirement for long-term monitoring after the project has been completed, resulting in a lack of information about the success or failure of certain restoration techniques (Selvakumar et al., 2010). Reasons include poor planning and lack of allocated funding. A carefully designed program for strategically monitoring restoration projects to determine which methods in which settings are most ecologically effective is urgently needed (Palmer et al., 2005).

Stream restoration describes a set of activities that help improve the environmental health of a stream. It is the re-establishment of the general structure, function and self-sustaining behavior of the stream system that existed prior to disturbance (Gilman et al 2009). It is a holistic process that requires consideration of all physical and biological components of the stream system and its watershed. Improved health may be indicated by expanded habitat for diverse species (e.g. fish, aquatic insects, wildlife) and reduced impacts to habitat features (MCDEP, 2010). Enhancements may also include improved water quality (i.e. reduction of pollutant levels and increased dissolved oxygen levels) and achieving a self-sustaining, functional flow regime in the stream system that does not require periodic human intervention, such as dredging or construction of flood control structures (Gilman et al., 2009).

The effective evaluation of project success should include; clear objectives that provide a framework for the design and evaluation of a project; baseline data that supports an observable estimate of ecosystem changes caused by the project and that encompasses both the pre and post-project period (including a detailed historical study); a robust study design that can demonstrate the effects of restoration projects in a complex stream system; a commitment to long term monitoring to detect effects evident only years following project completion, and; a willingness to acknowledge failures in restoration goals and objectives as these failures can provide valuable insight and lessons learned to adapt restoration and monitoring design (Kondolf, 1995).

Many stream restoration projects do not include a requirement for long-term monitoring after the project has been completed, resulting in a lack of information about the success or failure of certain restoration techniques (Selvakumar et al., 2010). In some cases no post-project evaluation has been conducted, while in others, a lack of advanced planning has caused evaluation results to be of little use in determining whether or not project objectives have been satisfied. To date, no general guidelines for the evaluation of stream restoration projects have been developed and implemented. Such guidelines are needed to facilitate the study of past restoration successes and failures so that the practice of stream restoration can be improved and further validated as a viable activity (Bernhardt et al., 2005; Bernhardt et al., 2007; Miller et al., 2009; Palmer et al., 2005; Roni et al., 2002).

1.1 Kama Creek Restoration Project

The need for restoration attention on Kama Creek was first identified in 1991 through the Nipigon Bay Remedial Action Plan (Nipigon Bay Remedial Action Plan, 1995). Kama Creek is located on the North Shore of Lake Superior (See Figure 1.1) and was a historically significant habitat for large numbers of Coaster Brook Trout, *Salvelinus fontinalis* in Lake Superior (Schreiner at al. 2008).

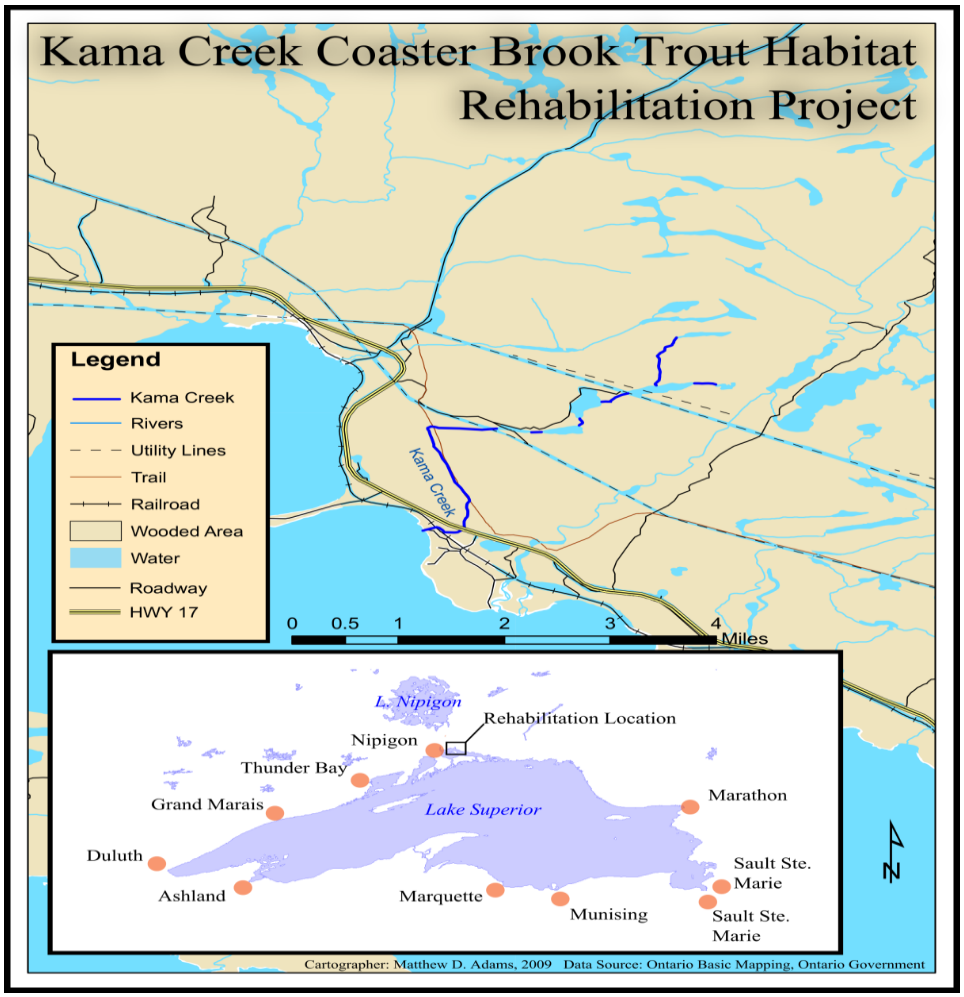


Figure 1.1 Location of Kama Creek, North Shore of Lake Superior, Ontario Canada.

However, in the mid 1960s, erosion concerns at a railway stream crossing prompted the realignment of the lower reach of the creek downstream of the railroad crossing. This diversion caused a loss of approximately 300 meters of brook trout habitat, increased the velocity of the stream flow, reduced the sinuosity and cascading pools in the stream channel and created a barrier to fish migration, blocking access to 1.5km of fish habitat in the upper reaches of the creek. Before the realignment of the creek, brook trout populations in river systems similar to Kama Creek were estimated to be above average for the North Shore of Lake Superior. Since the realignment, the brook trout have been reduced in the creek and their populations within Nipigon Bay have been dramatically degraded (Rob Swainson Pers. Commun., 2010). The impacts to Kama Creek have been identified as contributors to fish population and fish habitat impairments in the Nipigon Bay Area of Concern (Nipigon Bay Remedial Action Plan Report. 1995).

Population data for coaster brook trout in Lake Superior is limited, however D'Amelio and Wilson (2008) estimated that there were over 106 tributaries on Lake Superior that have supported coaster brook trout populations. The majority of research has focused on Nipigon Bay, the Upper Peninsula and Isle Royale (Newman and DuBois, 1997). The largest populations (size and abundance) are found in Nipigon Bay tributaries, however all coaster brook trout populations in Lake Superior are considered remnant stocks and are of concern to conservation biologists (Huckins et al., 2008). Remnant stocks could be as low as 300 adult individuals per spawning area within Nipigon Bay (i.e. the area encompassing the proposed Kama Creek restoration project), and total populations in the bay could be as low as 1000-2000 adult individuals (Swainson MNR Nipigon District Biologist, personal communication).

Habitat use and movement patterns of coaster brook trout in Nipigon Bay have been observed at over 600 locations and 90% of these sites are found within shallow nearshore areas where the coasters can ascend small tributaries nearby (Mucha and Mackereth, 2008). The coasters benefit thermally from the cool groundwater fed springs within these small tributaries and the habitat is ideal for spawning and nursery to ensure the survival of hundreds of fry.

Based on the evidence that a significant proportion of the remaining Lake Superior coaster populations rely on spawning and nursery in tributaries of the Nipigon Bay, these tributaries are the highest priority habitats to protect, particularly those with major inflows of groundwater, such as Kama Creek.

The rehabilitation activities on Kama Creek were carried out in October 2011 and included 3 major outcomes: 1.The reinstatement of Kama Creek and its floodplain to its original configuration (increased sinuosity, natural floodplain, in-stream variability, cascade-pools and spawning and nursery habitat); 2. An increase in the coaster brook trout populations as a result of providing an additional 300m of spawning, nursery and feeding habitat, and; 3. Direct contributions to the goals of Lake Superior conservation plans (i.e. Brook Trout Rehabilitation Plan for Lake Superior) and fulfillment of the recommended action to restore the fish habitat and fish population in the Nipigon Bay Remedial Action Plan process. The effective removal of the migration barrier and the subsequent restoration of approximately 600m^2 of spawning habitat may increase the coaster brook trout population in Nipigon Bay significantly, since Kama Creek has long been identified as one of the critical spawning and nursery regions of the bay. Monitoring of the project was required for three years following restoration. Success can be measured by the increase in biological productivity of the creek as compared to baseline data collected in this study.

1.2 Purpose and Objectives of the Research

The primary purpose of this research is to describe how the Kama Creek Restoration Project has improved the environmental health of a small-scale stream, and improved coaster brook habitat in Nipigon Bay. This will be achieved by establishing clear goals for evaluating the success of the Kama Creek Restoration Project and by developing recommendations on the appropriate parameters, methodologies and data collection timelines required for long-term monitoring of a small catchment stream following restoration. Specifically, the research will address three objectives:

a) To establish success criteria for the Kama Creek Restoration Project;

b) To collect baseline and post-restoration stream data;

c) To evaluate the re-establishment of the restored stream and provide recommendations for long-term monitoring.

This research promotes a natural channel design approach to stream restoration. It provides a case-study reference and guidance document for natural resource professionals who plan, design, review and implement stream-restoration projects. Specifically, this research should provide a useful dataset and possible template for aiding in future effectiveness monitoring of the Kama Creek Restoration Project, and other potential small-scale stream restoration projects seeking to improve brook trout habitat on the Great Lakes.

1.3 Methods and Results

Field data for this study was collected during 2011 and 2012 to establish goals/objectives and to record baseline data pre and post construction on the Kama Creek. General observations and spot measurements were continued in 2013 and 2014 to confirm the assumptions drawn from the results of the 2012 data collection. Pre-project baseline conditions were documented immediately before project construction and included continuous climate data (temperature and precipitation), continuous stream levels, water quality sampling, fish surveys, and a habitat assessment protocol. The same data was collected after the stream restoration project, and compared to the baseline data in order to interpret the health and improvements of the system and to provide long-term monitoring recommendations.

This monitoring data not only provides insight to decisions that affect the coaster populations in and around Kama Creek, but the 'knowledge of these attributes is also important for understanding the basic population ecology that is critical for coaster conservation and management' (Huckins, et al., 2008: 1362).

CHAPTER 2

LITERATURE REVIEW

The body of Literature that has been reviewed in this chapter covers the key processes involved in monitoring stream restoration from historical approaches to modern design and methodologies used today. It covers methodologies used to monitor a restoration project and the criteria that can be used to demonstrate that the stream system is improving.

2.1 Growth of Stream Restoration Projects

Stream restoration projects are rapidly growing and becoming a multibillion dollar industry, but the need for systematic post-project evaluation, particularly for small-scale projects is still evident. (Bernhardt et al., 2005; Henry et al., 2002; Palmer et al 2014; Purcell et al., 2002; and Roni, 2005). Bernhardt et al. (2007) found almost half of all restoration projects were initiated due to the stream system being degraded, with improving in-stream habitat often stated as a primary goal. Despite the significant amount of money and effort committed to stream restoration there has been limited effectiveness monitoring, particularly in terms of biological responses (Roni et al. 2002; Bernhardt et al. 2005; Miller et al. 2009). The need for improving approaches to post-project evaluation is illustrated by recent restoration surveys. The National Rivers Authority found that, of nearly 100 enhancement projects completed on British rivers, only five had been the subject of post-project evaluation reports (Holmes 1991). In North America, evaluations of aquatic and riparian restoration projects have been conducted on a regional basis. O'Neil and Fitch (1992) examined 400 in-stream aquatic habitat enhancement structures installed in southwestern Alberta between 1982 and 1990 and found that while 69%

where structurally stable 33% were of low or zero effectiveness in achieving habitat enhancement goals. Whiteway et al. 2010 examined data from 211 stream restoration projects and found a significant increase in pool area, average depth, large woody debris, and percent cover, as well as a decrease in riffle area, following the installation of in-stream structures. There was also a significant increase in salmonid and biomass following the installation of structures such as weirs, deflectors, cover structures, boulder placement, and large woody debris.

While it is evident that monitoring and evaluation are important, several obstacles do exist. Traditionally resource management has focused on the data collection and does not include development of a monitoring plan to assess the project goals (Grumbine, 1997).

Project managers receiving hydraulic project approvals (HPAs) in Washington State were surveyed to determine whether monitoring was taking place on projects. About half the project managers surveyed reported the collection of baseline data and the use of biological, physical, chemical, or other water quality measures for their projects. Of those who reported collection of monitoring data only 18% indicated that monitoring was required. Project managers with projects focusing on engineering goals (e.g., roadbed stabilization) were less likely than other project managers to collect baseline monitoring data. Project managers with projects focusing on restoration/ecological or fisheries goals were more likely than other project managers to collect monitoring measures (Bash and Ryan, 2002).

2.2 Historical Approaches

Historically in stream restoration management the paradigm has been an engineering dominated form of stream control or improvement. Engineers have relied heavily on the use of rigid engineering measures for instream construction and stabilization projects since these techniques have relatively well defined material properties, design guidelines, and construction sequences (Johnson et al., 2002). Roughness elements, such as riparian vegetation and woody debris, were considered to produce messy, complex and irregular channels that created uncertainty and reduced predictability in what was allegedly a controlled environment (Montgomery and Piégay, 2003). The limited integration of geomorphological understanding often resulted in engineering practices targeting the symptoms rather than the underlying causes of stream change (Leeks *et al.*, 1988; Rutherfurd *et al.*, 1998). Of the aquatic habitat enhancement projects evaluated to date a large portion were found to have failed outright (Frissel and Nawa, 1992; O'Neil and Fitch, 1992). Success was most likely to be assessed in terms of one or two objectives, such as power generation, ease of navigation or flood hazard reduction, rather than as the balancing of a range of priorities (Millington, 2002). Furthermore, one-sided goals were pursued such as the enhancement of fish habitat for species of interest to sports fishing (Muhar et al., 1995). The River Murr project in Baden-Wilrttemberg, Germany provides an example of a one-sided procedure. Despite an enormous improvement in the habitat conditions, an overall strategy was missing. The poor water quality of River Murr, for example, prevented the appearance of more sensitive species and the development of a balanced fish stock (Muhar et al. 1995). These strategies are not the most efficient and cost-effective way to achieve rehabilitation success (Kondolf, 1998). Ultimately the failure of this paradigm has been well documented in terms of its harmful impacts on stream health and in the lack of community participation (Kingsford, 1995; Dovers, 2001; (Purcell et al., 2002; Selvakumar et al., 2010; Palmer et al. 2014).

2.3 Recent Approaches

The new approach by river ecologists and geomorphologists has promoted a more holistic view of landscapes in catchment-scale thinking about stream rehabilitation programs, seeking to integrate spatial and temporal dimensions of change (e.g., Frissell *et al.*, 1986 and Bravard *et al.*, 1999). Such approaches focus attention on the physical and ecological integrity of living, variable, dynamic and evolving systems (Everard and Powell, 2002). Rather than aiming to restore stream systems to some real or imagined pre-engineered state, emphasis is placed on adoption of measures that strive to maintain or improve ecological health and are able to monitor ecological processes and measures of ecosystem functionality (Cullen, 1997). The ecosystem-based approach to stream rehabilitation strives to heal river systems through enhancing natural recovery mechanisms (Gore, 1985 and Koehn *et al.*, 2001).

An emerging emphasis in river restoration research is to include the restoration of ecological functions. This is in part related to a push by ecologists for a more comprehensive process-based restoration (Beechie et al. 2010), i.e., one that goes beyond hydrogeomorphic processes to include restoration of ecological processes. (Bernhardt et al. 2005, Kondolf et al. 2006). Thus, functional ecological restoration includes efforts specifically targeted at restoring critical structural ecosystem features (e.g., riparian vegetation) and critical ecological processes, such as nutrient dynamics (e.g., flux or uptake of nutrients), the input of organic matter, and productivity (Beechie et al. 2010, Bernhardt & Palmer 2011). Which processes and structures are most critical to restore vary depending on what the stressors are for a particular channel and which of those stressors must be reduced or removed for the project to be successful over time.

2.4 Evaluating Stream Restoration: Success Criteria and Monitoring Needs

The lack of systematic post-project evaluation may be due to inherent difficulties in measuring stream restoration success. Often, post-project evaluation criteria and techniques are not considered until after the project is designed and implemented. Evaluation success criteria should be developed based on historical information and data gathered from the project site and applicable reference sites using proposed evaluation techniques (Bash and Ryan, 2002). In some cases, one criterion may serve as an indicator for multiple objectives.

Currently, the measure of success focuses on the implementation of a mitigation plan that may not conduct any evaluation for the ecological integrity of the streams being restored. Also, since the plans may differ from project to project, it is hard to establish a set of criteria that can be consistently applied to measure the success of various stream restoration projects. Ryder and Miller (2005) propose the use of quantitative ecological indicators to measure the success of stream restoration. In contrast, Ehrenfeld (2000) proposes that restoration goals should be project specific. Restoration does not guarantee the recreation of a “natural” system and the limitations of a restoration project should be recognized at the outset.

Stream assessments are suggested as an alternative. If modified to include a biological assessment, these could provide the foundation to determine the success or failure of restoration projects. As the success criteria continue to be debated among the restoration community, it is critical that funding agencies take the first step in requiring a minimum of monitoring and evaluation for all restoration projects along with the development of these criteria (Kondolf, 1994). Due to the change in stream characteristics over time, universal success criteria will not be agreed upon. Success criteria designed for a specific project may be more realistic.

Another frequent criticism of existing stream restoration practices is that the monitoring and evaluation are not standardized. Current monitoring tends to focus on the physical response to stream restoration techniques but it is the biological response that will measure the effectiveness of the restoration (Roni et al., 2002; Palmer et al., 2005). To improve restoration practices, it is critical that restoration projects include an appropriate monitoring and evaluation plan because the knowledge gained is helpful to the design of future projects (Kondolf, 1994; Kondolf and Micheli, 1995; Bash and Ryan, 2002). Sponsors of restoration projects may conduct monitoring of stream conditions after construction to evaluate effectiveness. In some projects it may take considerable time before there is evidence of biological activity, such as fish spawning. Therefore monitoring efforts may be performed for several years after a restoration project has completed (MCDEP, 2010).

2.4.1 Developing Goals and Success Criteria

The first step in developing a monitoring plan is to determine the goals and objectives of the restoration project. Clearly defining goals and objectives of the project is critical to determining the key questions (Roni, 2005). Objectives are evaluated on the basis of design or success criteria. These standards or criteria are conceived in large part from an understanding of the reference ecosystem. Success criteria provide an empirical basis for determining whether or not project objectives have been attained (Roni, 2005). Table 2.1 shows some examples of success criteria Harris (2005).

Table 2.1. Sample Success Criteria and Monitoring Parameters used for the Kama Creek Restoration Project Types (Harris, 2005) and (Palmer et al. 2014).

Restoration Parameter	Example Success Criteria	Example Monitoring Parameter(s)
Instream habitat improvement	Project improves rearing habitat within restored reach	Frequency and depth of pools, water quality and temperature
Streambank Stabilization	Reduced bank erosion	Percent of bank that is fully vegetated, discharge and level
Riparian Planting/control	Survival meets or exceeds contract specification, Reduced bank erosion	Amount of native vegetation present
Fish Passage Improvement	Area of habitat made accessible, sign of Fish using stream habitat above culvert/railway	amount of habitat made accessible and fish surveys to show presence
Substrate Improvement	Substrate size within ideal range for brook trout	Pebble counts
Ecosystem metabolism, riparian plants, macroinvertebrate assemblages, fish populations	Primary and secondary production at levels comparable to reference systems	Gross primary production, respiration, growth, survival, and age structure of plantings, macroinvertebrates, and fish species of interest
Nutrient processes	Rates of biogeochemical processes appropriate to support biota and maintain material fluxes supportive or protective of nearby ecosystems	Nutrient fluxes combined with standing stocks: nutrient storage, turnover, export, assimilatory uptake, denitrification, nitrogen fixation, phosphorus release from sediments, etc.
Channel form and in-channel structure	Sufficient suitable habitat to support species	Pool: riffle sequence, sinuosity, discharge, spatial heterogeneity, streambed particle size distribution (D84:D50), large woody debris, macrophyte cover, bank refugia

Note:Adapted from http://forestry.berkeley.edu/comp_proj/DFG/Monitoring%20Implementation%20Effectiveness%2Fisheries.pdf Procedures for Monitoring the Implementation and Effectiveness of Fisheries Habitat Restoration Projects and Palmer et al. 2014.

If data collected during monitoring shows that success criteria have been met there can be no doubt that project objectives were achieved. The restored ecosystem is likely to be sufficiently resilient to require little or no further assistance from the restoration practitioner (SER, 2004).

In one study Palmer et al. (2005) designs five criteria that can be used to determine if a project is a success or failure ecologically. First, the design of an ecological river restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site. Secondly, the river's ecological condition must be measurably improved. Thirdly, the river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed. Fourthly, during the construction phase, no lasting harm should be inflicted on the ecosystem. Fifthly, both pre- and post-assessment must be completed and data made publicly available.

Another study based on Woolsey et al. (2009) used a set of guidelines for selecting potential success indicators. An example of an indicator may be quantity of large woody debris or short-term leaf retention capacity. These indicators could measure the success of refugia as a criteria. If an instream structure is intended to improve rearing habitat, on the other hand, the desired changes could be expressed in terms of pool frequency, instream cover and/or pool depth or other measurable environmental characteristic (Harris, 2005). These should be stated as desired pool frequency e.g., 50 percent of reach length, desired instream cover percentage, e.g., 25 percent shelter ratings or desired pool depth e.g., less than three feet, in order to provide clear performance measurements (Washington Salmon Recovery Board 2003).

2.5 Monitoring Protocols and Parameters

The appropriate use and, therefore, potential success of a monitoring strategy is largely dependent upon the type initiative undertaken (Roni, 2005). In order to design an appropriate monitoring strategy careful consideration must be taken in determining which type is best suited for a particular monitoring initiative. Ryder and Miller (2005) suggest that the Hobbs and Harris (2001), Harris (2003), and Lake (2005) perspective of utilizing ecological/stability based techniques to evaluate system structure does not indicate a viable system. Those that support the Ryder and Miller (2005) view, suggest that biological communities in ecosystems provide the indicators necessary to suggest whether a restoration activity can be deemed as successful. Due to ecological restoration's diverse background, conflicting views of how to approach the various dilemmas found within the field are common and to be expected.

The assessments performed by many include a general description of the site, a physical characterization and water quality assessment, and a visual assessment of instream and riparian habitat quality. Together these data provide an integrated picture of several of the factors influencing the biological condition of a stream system (Barbour et al. 1999). These assessments are not as comprehensive as needed to adequately identify all causes of impact and an additional investigation into hydrological modification of water courses should also be included (Shields et al. 2003).

2.5.1 Habitat Assessment

An evaluation of habitat quality is critical to any assessment of ecological integrity and should be performed at each site at the time of the biological sampling. In general, habitat and biological diversity in rivers are closely linked (Raven et al. 1998). In the truest sense, "habitat" incorporates all aspects of physical and chemical constituents along with the biotic interactions. In these protocols, the definition of "habitat" is narrowed to the quality of the instream and riparian habitat that influences the structure and function of the aquatic community in a stream (Karr et al. 1986).

Presently, a number of different indicators have been utilized to pursue accurate assessment of river restoration projects. Lepori et al. (2005b) utilized benthic macroinvertebrate sampling to assess the effectiveness of in-stream structures. Geomorphic indicators of percent moisture, vegetation cover, and substrate have also been recommended in Roni et al. (2005). Another strategy commonly adopted by southwestern Ontario conservation authorities are the Rapid Bioassessment Protocols, a highly qualitative personal judgement based activity. The Rapid Bioassessment Protocols (RBPs) are essentially a mixture of existing methods that have been employed by various State Water Resource Agencies (e.g., Ohio Environmental Protection Agency [EPA], Florida Department of Environmental Protection [DEP], Delaware Department of Natural Resources and Environmental Control [DNREC], Massachusetts DEP, Kentucky DEP, and Montana Department of Environmental Quality [DEQ]) (Barbour et al. 1999). The original Rapid Bioassessment Protocols were designed as inexpensive screening tools for determining if a stream is supporting or not supporting a designated aquatic life use. The habitat quality evaluation, included in the Rapid Bioassesssment Protocols, can be accomplished by characterizing selected physicochemical parameters in conjunction with a systematic assessment of physical structure.

For streams, an encompassing approach to assessing structure of the habitat includes an evaluation of the variety and quality of the substrate, channel morphology, bank structure, and riparian vegetation (Southwood, 1977). The habitat assessment matrix developed for the Rapid Bioassessment Protocols (RBPs) in Plafkin et al. (1989) were originally based on the Stream Classification Guidelines for Wisconsin developed by Ball (1982) and “Methods of Evaluating

Stream, Riparian, and Biotic Conditions" developed by Platts et al. (1983). Barbour and Stribling (1991, 1994) modified the habitat assessment approach originally developed for the RBPs to include additional assessment parameters for high gradient streams and a more appropriate parameter set for low gradient streams. All parameters are evaluated and rated on a numerical scale of 0 to 20 (highest) for each sampling reach. The ratings are then totaled and compared to a reference condition to provide a final habitat ranking. Scores increase as habitat quality increases. To ensure consistency in the evaluation procedure, descriptions of the physical parameters and relative criteria are included in the rating form.

Habitat evaluations are first made on instream habitat, followed by channel morphology, bank structural features, and riparian vegetation. Generally, a single, comprehensive assessment is made that incorporates features of the entire sampling reach as well as selected features of the catchment. Additional assessments may be made on neighboring reaches to provide a broader evaluation of habitat quality for the stream ecosystem (Barbour et al, 1999). The actual habitat assessment process involves rating the 10 parameters as optimal, suboptimal, marginal, or poor based on the criteria. Some state programs, such as Florida Department of Environmental Protection (DEP) (1996) and Mid-Atlantic Coastal Streams Workgroup (MACS) (1996) have adapted this approach using somewhat fewer and different parameters. The 10 parameters measured are epifaunal substrate or available cover, pool substrate characterization, pool variability, sediment deposition, channel flow status, channel flow alteration, frequency or riffles or bends, channel sinuosity, bank stability, bank vegetation protection, riparian vegetation zone width. Table 2.2 below shows a description of each parameter and its importance for stream habitat as described in Barbour et al (1999).

Table 2.2 Description and importance of parameters measured in a Habitat Assessment

Condition Category	Description of parameter	Importance in stream habitat	Reference(s)
Epifaunal Substrate/ Available Cover	Includes the relative quantity and variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs and branches, and undercut banks, available as refugia, feeding, or sites for spawning and nursery functions of aquatic macrofauna	A wide variety and/or abundance of submerged structures in the stream provides macroinvertebrates and fish with a large number of niches, thus increasing habitat diversity. Riffles and runs are critical for maintaining a variety and abundance of insects in most high-gradient streams and serving as spawning and feeding refugia for certain fish.	Wesche et al. 1985, Pearsons et al. 1992, Gorman 1988, Rankin 1991,Barbour and Stribling 1991, Plafkin et al. 1989, Platts et al. 1983
Pool Substrate Characterization	Evaluates the type and condition of bottom substrates found in pools.	Firmer sediment types (e.g., gravel, sand) and rooted aquatic plants support a wider variety of organisms than a pool substrate dominated by mud or bedrock and no plants. In addition, a stream that has a uniform substrate in its pools will support far fewer types of organisms than a stream that has a variety of substrate types	Beschta and Platts 1986, U.S. EPA 1983
Pool Variability	Rates the overall mixture of pool types found in streams, according to size and depth.	Rivers with low sinuosity (few bends) and monotonous pool characteristics do not have sufficient quantities and types of habitat to support a diverse aquatic community	Beschta and Platts 1986, U.S. EPA 1983
Sediment Deposition	Measures the amount of sediment that has accumulated in pools and the changes that have	Sediment deposition may cause the formation of islands, point bars (areas of increased deposition	MacDonald et al. 1991, Platts et al. 1983, Ball 1982, Armour et al. 1991, Barbour and Stribling

	occurred to the stream bottom as a result of deposition. Deposition occurs from large-scale movement of sediment	usually at the beginning of a meander that increase in size as the channel is diverted toward the outer bank) or shoals, or result in the filling of runs and pools. High levels of sediment deposition are symptoms of an unstable and continually changing environment that becomes unsuitable for many organisms	1991, Rosgen 1985
Channel Flow Status	The degree to which the channel is filled with water	When water does not cover much of the streambed, the amount of suitable substrate for aquatic organisms is limited. In high-gradient streams, riffles and cobble substrate are exposed; in low-gradient streams, the decrease in water level exposes logs and snags, thereby reducing the areas of good habitat. Channel flow is especially useful for interpreting biological condition under abnormal or lowered flow conditions.	Rankin 1991, Rosgen 1985
Channel Alteration	Is a measure of large-scale changes in the shape of the stream channel	Artificially straightened streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally meandering streams. Channel alteration is present when artificial embankments, riprap, and other forms of artificial bank stabilization or structures are present	Barbour and Stribling 1991, Simon 1989a, Simon and Hupp 1987, Hupp and Simon 1986, Hupp 1992, Rosgen 1985, Rankin 1991, MacDonald et al. 1991
Frequency of Riffles (or Bends)	Is a way to measure the sequence of riffles and thus the heterogeneity	Riffles are a source of high-quality habitat and diverse fauna, therefore,	Hupp and Simon 1991 Platts et al. 1983, Rankin

	occurring in a stream	an increased frequency of occurrence greatly enhances the diversity of the stream community	1991, Rosgen 1985
Channel Sinuosity	Evaluates the meandering or sinuosity of the stream	A high degree of sinuosity provides for diverse habitat and fauna, and the stream is better able to handle surges when the stream fluctuates as a result of storms	Hupp and Simon 1991 Platts et al. 1983, Rankin 1991, Rosgen 1985
Bank Stability (condition of banks)	Measures whether the stream banks are eroded (or have the potential for erosion).	Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks, and are therefore considered to be unstable. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. Eroded banks indicate a problem of sediment movement and deposition, and suggest a scarcity of cover and organic input to streams.	Ball 1982, MacDonald et al. 1991, Armour et al. 1991, Barbour and Stribling 1991, Hupp and Simon 1986,
Bank Vegetation Protection	Measures the amount of vegetative protection afforded to the stream bank and the near-stream portion of the riparian zone	The root systems of plants growing on stream banks help hold soil in place, thereby reducing the amount of erosion that is likely to occur. This parameter supplies information on the ability of the bank to resist erosion as well as some additional information on the uptake of nutrients by the plants, the control of instream scouring, and stream shading. Banks that have full, natural plant growth are better for fish and macroinvertebrates than are banks without vegetative protection or	Platts et al. 1983, Hupp and Simon 1986, 1991, Simon and Hupp 1987, Ball 1982

		those shored up with concrete or riprap	
Riparian Vegetation Zone Width	Measures the width of natural vegetation from the edge of the stream bank out through the riparian zone.	The vegetative zone serves as a buffer to pollutants entering a stream from runoff, controls erosion, and provides habitat and nutrient input into the stream. A relatively undisturbed riparian zone supports a robust stream system	Barton et al. 1985 Platts et al. 1983, Rankin 1991, Barbour and Stribling 1991

Note: Adapted from (Barbour et al. 1999)

Optimal brook trout stream habitat is characterized by clear, cold spring-fed water a silt-free rocky substrate in riffle-run areas; an approximate 1:1 pool riffle ratio with areas of slow deep water; well vegetated stream banks; abundant instream cover and relatively stable water flow, temperature regimes, and stream banks. Stream conditions should consider these parameters when monitoring for sustainable brook trout habitat (Webster 1975).

Excessive or accelerated bank erosion is considered a poor condition for habitat quality in this assessment, though some bank erosion is important to the functioning of river ecosystems and is a geomorphic process that promotes riparian vegetation succession and creates dynamic habitats crucial for aquatic and riparian plants and animals (Florsheim et al. 2008). For example, during floods bank erosion delivers large woody debris to channels (Piegay et al. 1999, Sudduth and Meyer 2006). Bank erosion is especially common and erosion rates are highest on the outside of river bends where fluvial processes, mass wasting, and undercutting of riparian vegetation leads to meandering (Leopold and Wolman 1957, Johannesson and Parker 1989). Bank erosion that facilitates meandering and creation of abandoned channels is important because it leads to vegetation succession which is necessary for riparian diversity (Salo et al. 1986).

2.5.2 Water Quality in Respect to Fish Habitat Requirements

Within the context of stream rehabilitation for aquatic life there are several important water quality parameters to monitor. Relative water quality can be obtained for a body of water through the use of governmental guidelines such as the US-EPA and Canadian Environmental Quality Guidelines (CEQG). Generally, water quality is not measured in one single location on a body of water, especially when considering a riverine environment. The dispersion of sample points helps to mitigate the potential for an inaccurate characterization of the water body (Chapman 1996). Some parameters measured will vary temporally, such as pH and dissolved oxygen. Proper sampling and analysis can account for these variations (CCME 1999; Chapman 1996; and EPA 2002).

2.5.2.1 pH

Acidity, commonly referred to as pH, is extremely important in an aquatic environment. The acidity of water is a measure of the ratio of hydrogen (H^+) and hydroxyl (OH^-) ions in the solution (CCME 1999; Chapman 1996). Due to the logarithmic nature of the pH scale, minimal increases or decreases can affect water quality and make a body of water unsuitable for a resident species (CCME 1999). The optimal pH range for brook trout is 6.5-8.0, with a tolerance range of 4.0-9.5 (Raleigh, R.F.1982).

2.5.2.2 Dissolved Oxygen

Dissolved oxygen is another extremely important factor of water quality for aquatic life and is commonly measured in mg/L. Without dissolved oxygen, a body of water becomes eutrophic and unsuitable for fish and other aquatic life (Chapman 1996). Water temperature has an inverse influence on the dissolved oxygen in a body of water; as water temperature increases, dissolved oxygen decreases. The input of organic matter into a body of water is generally detrimental for dissolved oxygen (CCME 1999). A measure of dissolved oxygen can be used for an evaluation of organic waste pollution and biochemical oxygen demand in a body of water (Chapman 1996).

Brook trout normally require high oxygen concentrations with optimum conditions at dissolved oxygen concentrations near saturation and temperatures above 15° C. Local or temporal variations should not decrease to less than 5 mg/l (Mills 1971). Dissolved oxygen requirements vary with age of fish, water temperature, water velocity, activity level, and concentration of substances in the water (McKee and Wolf 1963). As temperatures increase, the dissolved oxygen saturation level in the water decreases, while the dissolved oxygen requirements of the fish, increases. As a result, an increase in temperature resulting in a decrease in dissolved oxygen can be detrimental to the fish. Optimum oxygen levels for brook trout are not well documented but appear to be ~ 7 mg/l at temperatures < 15° C and ~ 9 mg/l at temperatures ~ 15° C.

2.5.2.3 Temperature

Temperature is also an essential parameter with regards to aquatic ecosystems and chemical reactions within a water body. While temperatures will fluctuate seasonally, and even diurnally, they are usually influenced only through climatic factors (Chapman 1996).

Temperature directly affects other parameters such as dissolved oxygen and conductivity. The solubility of certain gases decreases with a warming of a water body (CCME 1999; Chapman 1996). Temperature is also important for the metabolic rates and growth of aquatic life. Plankton and bacterial growth can be accelerated greatly with an increase in temperature and rich nutrient conditions (Chapman 1996). Individual fish species also have an ideal temperature preference range. Some species may experience increased mortality if temperature fluctuates beyond tolerable levels (CCME 1999). The literature suggests that for brook trout, very brief exposure to water temperatures up to 22°C may be tolerated. However, populations are more stable and productive when water temperatures don't exceed 19°C. Typical brook trout habitat conditions are those associated with a cold temperate climate, cool spring-fed ground water and moderate precipitation (MacCrimmon and Campbell1969). Warm water temperatures appear to be the single most important factor limiting brook trout distribution and production (Creaser 1930; Mullen 1958; McCormick et al. 1972). The reported upper and lower temperature limits for adult brook trout vary. Bean (1909) reported that brook trout will not 1ive and thrive in temperatures warmer than 20°C. McAfee (1966) indicated that brook trout usually do poorly in streams where water temperature exceeds 20° C for extended periods. The overa1 temperature range of 0-24° C was observed by MacCrimmon and Campbell (1969), though this upper and lower tolerance limit probably does not reflect the range of temperatures that is most conducive to good growth. Baldwin (1951) cites an optimum growth rate at 14° C. Mullen (1958) gave the optimum temperature range for activity and feeding for brook trout as between 12.8°C and 19°C.

2.5.2.4 The total dissolved solids (TDS) and Conductivity

Total dissolved solids and conductivity in a body of water are also a valuable measure of water quality. The clarity and conductivity of the water column is directly influenced by the particulate matter in solution (CCME 1999). Conductivity, measured in microseimens [µS], measures the ability of water to conduct an electrical current (CCME 1999; Chapman 1996). Conductivity is related to the TDS and temperature in a water body. Conductivity can also be affected by the presence of nutrient ions such as potassium. Brook trout occur in waters with a wide range of alkalinity and specific conductance, although high alkalinity and high specific conductance usually increase brook trout production (Cooper and Scherer 1967). Conductivity of freshwater varies between 50 to 1500 hs/cm (Boyd, 1979). As fish differ in their ability to maintain osmotic pressure, therefore the optimum conductivity for fish production differs from one species to another. Sikoki and Veen (2004) described a conductivity range of 3.8 -10 µS/cm as extremely poor in chemicals, Stone and Thomforde (2004) recommended the desirable range 100-2,000 µS/cm and acceptable range 30-5,000 µS/cm for fish culture. Typically, the TDS value in mg/L is about half of the Conductivity (µS/cm) Stone and Thomforde (2004). Small size in trout has been attributed to low TDS values less than 20 ppm, (Lennon 1967).

2.5.3 Instream techniques: Flow, Discharge, Substrate

Minimal research has been conducted on post-restoration monitoring that contains both ecological and fluvial geomorphic approaches to evaluation (Yates, 2008). Modifications to a stream channel may be appropriate to address degradation. Channel modifications may yield improved habitat for wildlife and plants in a stream corridor, but can result in flooding, excessive erosion or other damage if not carefully planned. Design of modifications involves a careful analysis of a complex fluvial process (WDFW, 2004). Alterations may include channel shape (in terms of sinuosity and meander characteristics) and cross-section and channel profile (slope along the channel bed). Alterations affect the dissipation of energy through the channel, which has an impact on stream velocity and turbulence, sediment volume and size distribution, scour, and water surface elevations. These should be monitored before and after a restoration project (WDFW, 2004). Indices have also been developed that measure the stability of stream channels (Rosgen 2001).

Rosgen developed the Natural Channel Design (NCD) and presents a stream and river classification system that is founded on the basis that dynamically-stable stream channels have a morphology that provides appropriate distribution of flow energy during storm events.
Further, he identifies 8 major variables that affect the stability of channel morphology, but are not mutually independent: channel width, channel depth, flow velocity, discharge, channel slope, roughness of channel materials, sediment load and sediment particle size distribution.
When streams have one of these characteristics altered, some of their capability to disperse energy properly is lost (Leopold et al. 1964, Rosgen 1985) and will result in accelerated rates of channel erosion. Rosgen's Natural Channel Design (NCD) claims to restore the chemical, physical, and biological functions of a river that is self-regulating and exhibits a stable channel (Rosgen 2011), yet the method does not address chemical or biological processes (Palmer et al. 2014).

A fairly well-defined group of academic scientists have pushed for a process-based approach to channel design instead of the form-based classification approach of Rosgen (Simon et al. 2007). However, the focus in this approach still centers on channel morphology (Palmer et al. 2014).

Most stream restoration projects today are implemented with a primary focus on channel form or physical structures rather than on ecological processes (Lake et al. 2007, Wortley et al. 2013). Channel width, depth, and slope are manipulated such that, the channel will not aggrade or degrade under the local hydrogeomorphic conditions. A number of failures, as well as strong critiques of channel design for stability and the Rosgen NCD approach (Buchanan et al. 2012, Lave et al. 2010, Simon et al. 2007), have encouraged some hydrologists and geomorphologists to broaden the focus from fixed channel form to including the concept of a dynamic equilibrium in which the channel is free to change over time (Kline and Cahoon 2010, Wheaton et al. 2008).

The most important stream process in defining channel form according to Rosgen (2001) is the bankfull discharge. Bankfull discharge is the flow that transports the majority of a stream's sediment load over time and thereby forms and maintains the channel. Any flow that exceeds the stage of the bankfull flow will move onto the floodplain; therefore bankfull stage is considered the initial point of flooding (Stream Restoration, Natural Channel Design Handbook). This may or may not be the top of the streambank. If the stream has become incised due to changes in the watershed or streamside vegetation, the bankfull stage may be a small bench or scour line on the streambank. Recording Level and taking flow measurements will help to predict the bankfull discharge.

Stream flow, or discharge, is the volume of water flowing in a stream channel expressed as unit per time (cfs =cubic feet per second). Stream flow is an important determinant of water quality and aquatic habitat conditions. Elson (1939) reported that brook trout prefer moderate flows. Griffith (1972) reported that the focal point velocities for adult brook trout in Idaho ranged from 0.07m/s to 0.11m/s with a maximum of 0.25 m/sec. Minimum seasonal stream flow (typically late fall) often determines trout capacity in freestone streams. Cover for adult brook trout should be located in areas with water depths ≥ 15 cm and velocities of < 15 cm/s (MBTMP, 2006). According to Binns and Eisermann (1979) a base flow ≥ 55% of the average annual daily flow is considered excellent, 25–50% is fair, and < 25% is poor for maintenance of quality trout habitat .

Flow is the variable usually required for hydrological analysis but, continuous measurement of flow past a river section is usually impractical or prohibitively expensive. However, stage can be observed continuously or at regular short time intervals with comparative ease and economy. Fortunately, a relation exists between stage and the corresponding discharge at river section (How to Establish a Discharge Rating Curve, 1999). This relationship can be illustrated using a rating curve. A rating curve is established by making a number of concurrent observations of stage and discharge over a period of time covering the expected range of stages at the river gauging section (Buchanan and Sommers,1969). A simple rating curve is used in circumstances when the flow is contained to a main channel section and can be assumed to be fairly steady and the bed of the stream does not significantly change (How to Establish Stage Discharge Rating Curve, 1999). The rating curve is a very important tool in surface hydrology because the reliability of discharge data values is highly dependent on a satisfactory stage-discharge relationship at the gauging station or location of level logger (Herschy, 1995).

The composition of the stream bed (substrate) is an important factor in how streams behave. Observations tell us that steep mountain streams with beds of boulders and cobbles act differently from low-gradient streams with beds of sand or silt (Harrelson et al. 1994). Both hydraulic and physiographic studies of rivers often require some measure of the surface the channel. To provide an adequate description of bed material, a consistent method of sampling is necessary (Wolman, 1954). You can document this difference with a quantitative description of the bed material, called a pebble count. Wolman (1954) created the Wolman Pebble Count procedure for measuring substrate size and type. This technique requires the observer to measure sizes of random particles using a gravelometer. A step-toe procedure is frequently used to randomly select particles for quantification. The procedure is explained in various publications (Bevenger and King, 1995; Harrelson et al. 1994; Leopold et al. 1964) and is described below.

1. Select a reach for sediment particle size distribution quantification. For stream characterization, sample pools and riffles at the same proportion they occur in the stream reach.

2. Start transect at a randomly selected point (throw a pebble) along the edge of stream. Take one step into the water perpendicular to flow and, while averting your eyes, pick up the first pebble touching your index finger next to your big toe.

3. Measure the b-axis by determining which hole the pebble fits through in the gravelometer and record in data book.

4. Take another step across the stream and repeat the previous steps until you reach the opposite side. Establish a new transect and begin the process over again. If your stream reach is relatively narrow (<2 m), you can modify the method by walking upstream in a zig-zag pattern instead of perpendicular to flow. collect 100 measurements in order to accurately quantify pebble distributions.

Particles are tallied by using Wentworth size classes in which the size doubles with each class (2, 4, 8, 16, 32, etc.) or smaller class intervals based on 1/2 phi values (4, 5, 6, 8, 11, 16, 22, 32, etc.) (See Table 2.3) (Harrelson et al. 1994).

Table 2.3. Substrate Type and Size (Wentworth scale).

Substrate Type	Size Category
mud/silt	fine and smooth, not gritty
sand	0.2 - 2 mm (feels gritty)
gravels	2 - 60 mm
small cobbles	60 - 120 mm
large cobbles	120 - 250 mm
boulder	> 250 mm
Bed rock	bed of stream is comprised of solid rock

constructed	concrete

Note: Adapted from http://limnology.wisc.edu/courses/zoo548/Wolman%20Pebble%20Count.pdf

Scientists typically use the D50 and D84 as representative grain sizes for sediment: D50 is the median grain size and D84 the 84 the percentile used to represent the coarse fraction (50% and 84% of the sediment is finer than D50 and D84, respectively) (Bunte and Abt 2001). These are the grain sizes that are commonly used or comparison between sediment (e.g., is sediment getting coarser or finer downstream a river).

Bjornn and Reiser (1991) show that 13-128 mm preferred (movable) spawning substrate size range for salmon and trout species. Spawning substrate gravel should average between 0.3 8cm diameter with an optimal diameter of 3- 6 cm. Escape cover for juveniles and fry during winter and after emergence requires a substrate that is resistant to shifting and ranges in size from medium to large sized gravel, to small cobble. Brook trout often inhabit streams that receive ground water discharge (Threinen and Poff 1963), which helps to maintain suitable water temperatures throughout the summer. Reiser and Wesche (1977) stated that optimum substrate size for brook trout embryos ranges from 0.34-5.05 cm. Duff (1980) reported a range of suitable spawning gravel size of 30-80 mm in diameter for trout. Increases in sediment that alter gravel permeability reduce velocities and intergravel dissolved oxygen availability to the embryo and results in smothering of eggs (Tebo, 1975). In a California study, brook trout survival was lower where volumes of substrates less than 2.5mm in diameter increased (Burns 1970).

CHAPTER 3

METHODOLOGY FOR MONITORING STREAM RESTORATION SUCCESS

This chapter describes the methods used to establish baseline conditions in Kama Creek prior to creek restoration and to make post restoration comparisons with the newly restored channel. The primary field collection techniques consisted of a habitat assessment, water quality testing, fish surveys, discharge/level measurements and climate data. This data was conducted over 2 years between May and November of 2011 and 2012. Additional discharge data, fish survey data, water temperature and climate data and habitat assessment observations were collected again in 2013 and 2014 to further support the results of the two primary data collection years.

3.1 Study Site

Assessment of the stream took place in the Kama Creek watershed that drains into Nipigon Bay on the North Shore of Lake Superior (see Figure 1.1). The creek was well known locally, and by the district office of the Ontario Ministry of Natural Resources and Forestry, as significant habitat for large numbers of Coaster Brook Trout. In the mid 1960s, however, erosion concerns at a railway stream crossing prompted the realignment of the lower reach of the creek downstream of a railroad crossing. The diversion caused a loss of approximately 300 metres of brook trout habitat downstream of the railway tracks and created a barrier to fish migration past the railway tracks to an additional 1.16 km of fish habitat in the upper reaches of the creek. Figure 3. below is a aerial photograph showing the stream pre and post 1960's.

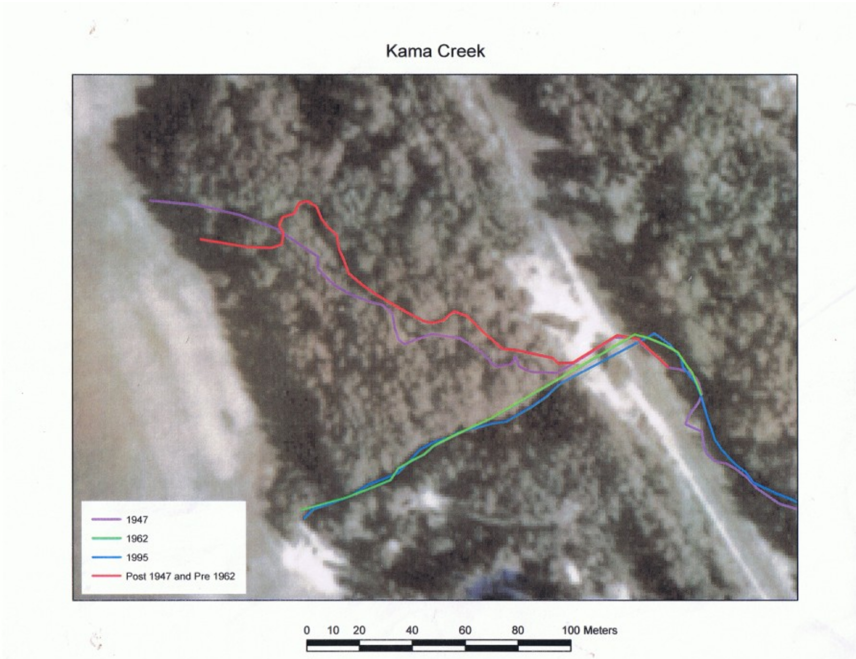


Figure 3.0 Aerial photograph showing Reach 2 pre 1960's before reconstruction and Reach 1 post 1960's.

Three reaches of the stream were monitored: reach 1, 2 and 3 (See Figure 3.1). Within each reach a site location was selected to collect all baseline data and was marked by a level logger. Prior to restoration activities the focus of the baseline data was placed on site 1 in 2011. This is within the portion of the stream that was diverted in the 1960s and where fish passage was cut off at the railway culvert (See Figure 3.2). A second site (site 3 in reach 3) was established above the culvert to determine the presence of fish before and after restoration and to act as a reference for discharge measurements for all years of the survey (See Figure 3.3). Post restoration data was collected (2012 and 2013) in site 2 (reach 2), the restored portion of the creek below the culvert (See Figure 3.4).

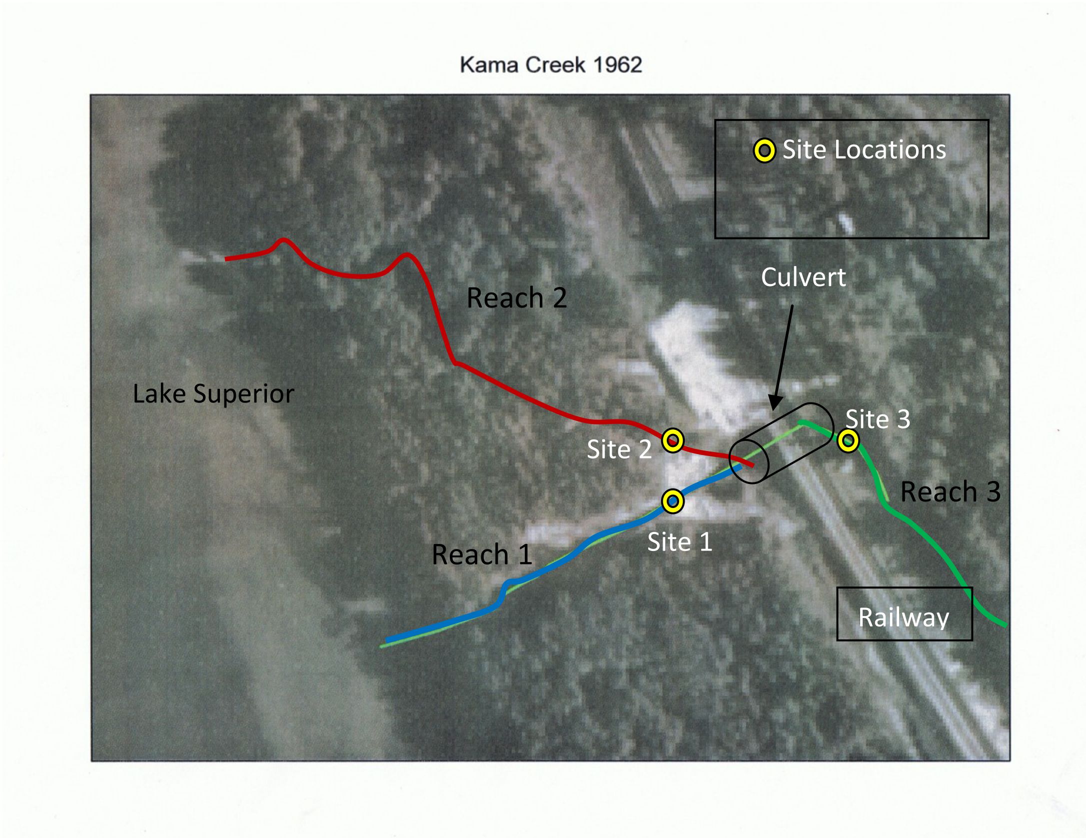


Figure 3.1. Location of study sites/reaches on Kama Creek.

Figure 3.2. Photo of reach 1, (left) the old straightened channel, and location of site 1, (right) within reach 1 near the culvert below the railway.

Figure 3.3. Location of reference site 3 on the other side of the culvert above the railway. Site 3 is located within reach 3 of the stream.

Figure 3.4 Photo of reach 2 (left) and location of site 2 (right) within reach 2, arrow pointing to level logger where data was collected.

3.2 Establishment of Baseline Conditions: pre and post construction

3.2.1 Habitat Assessment

Commonly used techniques to assess the "before and after" of stream restoration projects are habitat assessment and physicochemical techniques, such as those included in the Rapid Bioassessment Protocols (RBP) presented in Barbour et al. (1999). Habitat quality characteristics from Environmental Protection Agency's Rapid Bioassessment Techniques were also integrated in the assessment protocol used to evaluate Kama Creek. Using this guiding document, a Visually Based Habitat Assessment was completed in the summer of 2011 on the old channel and on the newly restored channel in 2012 and 2014. Habitat was assessed using 10 qualitative parameters and rated on a scale of 0-20, 20 being optimal conditions and 0 being poor conditions. These parameters were designed to characterize the quality of in-stream cover, substrate, flow, and riparian habitat. The habitat parameters evaluated were epifaunal substrate, pool substrate, pool variability, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, vegetative protection, and width of riparian vegetative zone. Table 3.1 below is a sample section of the data sheets used, showing the Riparian Zone Width parameter and the conditions in which to rank the stream. Other data was collected on the assessment day including air temperature, cloud cover, surface water temperature and GPS coordinates of location. Many photos were taken to later observe and confirm field notes of the visual assessment.

Table 3.1. Section of the Habitat Assessment Data Sheet

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor

10. Riparian Vegetative Zone Width	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12- 18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6- 12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

3.2.2 Water Quality Parameters

Water quality parameters were monitored to ensure that Kama Creek was meeting guidelines for the protection of aquatic life. Parameters were measured over a testing period from June to Nov in 2011 and 2012 to compare the old channel conditions to the new channel. Guidelines for the protection of aquatic life, such as the Canadian Environmental Quality Guidelines (CEQG) and fish habitat suitability guidelines, were used to assess whether the water quality in Kama Creek was healthy. The water quality parameters measured were temperature, specific conductivity, dissolved oxygen (DO), pH, and Total Dissolved Solids (TDS), shown in Table 3.2 below. Water chemistry data collected during the first year of monitoring was compared to the baseline data and to determine if the water chemistry met or exceeded standards established by the baseline data.

Table 3.2. Data Collection, Significance and Apparatus

Parameter	Significance	Collection Method
Temperature	Temperature is important for brook trout habitat as well as conductivity. Providing a baseline set of data of temperature will allow a better understanding of future	Handheld Unit

	changes.	
pH	Modified pH levels affect aquatic life and may be an indicator of pollution	Handheld Unit
Dissolved Oxygen	Important for both aquatic plants and fish. Indicator of the health of a body of water.	Handheld Unit
Conductivity	Primarily affected by the geology of the site, contaminants and organic pollutants increase conductivity levels. A baseline of conductivity data is useful to monitor potential pollution problems if a change is measured.	Handheld Unit
Total Dissolved Solids (TDS)	Affects the water balance of cells in aquatic organisms. Also affects water clarity, and may carry toxic compounds.	Handheld Unit
Discharge	May be an indicator of the size of the drainage pattern of the stream as well as the watershed size.	Measured with impeller and stream profile

Water chemistry was collected using handheld water quality units maintained and calibrated in the Department of Geography and the Environment at Lakehead University. Dissolved oxygen was measured using an EXTECH Instruments ExStik DO600 meter. Temperature, conductivity, total dissolved solids and pH were measured using a Hanna Instruments HI 98129 Combo meter. Data was collected in duplicate using two of each meter each field day to ensure good data quality and mitigate meter failures. Meters were recalibrated each week, in order to maintain an acceptable level of accuracy. The accuracies of each handheld meter are shown in Table 3.3.

Table 3.3 Accuracy of Handheld Water Quality Meters

Meter	Parameter	Accuracy
ExStick DO600	Dissolved Oxygen	±0.4mg/L
	Temperature	±1.0°C
	pH	±0.05 pH
Hanna HI 98129 Combo	Total Dissolved Solids	±2% of 0 to 2000 ppm
	Conductivity	±2% of 0 to 3999 µS/cm
	Temperature	±0.5°C

3.2.3 Water Temperature

Water temperatures were measured using temperature data loggers (Hobo Tidbits) located approximately 50 to 100 feet apart depending on the length of the reach (the longer the reach of stream farther spaced hobo loggers). Each Tidbit was attached to a brick and the brick was tied to a tree with rope, shown in Figure 3.6. The brick was placed within the center of the selected riffle or pool with the Tidbit hidden to avoid potential temperature fluctuations from direct sunlight and also to avoid vandalism. Detailed physical descriptions were recorded for each site and photographs were taken to facilitate recovery. All Tidbits were launched to record temperature every hour. Tidbits were retrieved every month. Data was downloaded on site using a laptop computer and stored as Microsoft Excel spreadsheets and text files for later analysis. These files were then merged and edited to remove erroneous readings (before launch and after retrieval) to create continuous data files for analysis. All habitat and point data was entered into a spreadsheet upon completion of the field season and data files were checked twice for errors.

Figure 3.6 Water Temperature Hobo set up and location in reach 2 of Kama Creek.

3.2.4 Fish Survey

Fisheries data was collected by electrofishing a portion of reach 1 and 3 (above the culvert) on June 2 of 2011 and reach 2 (newly restored reach) on July 23 of 2014. Electrofishing was not performed on reach 3 in 2014 due to some potentially dangerous conditions in the channel. This electrofishing procedure was performed by the researcher with the assistance of experienced Ministry of Natural Resources, Center for Northern Forest Ecosystem Research, employees (See Figure 3.7). Fish were collected in buckets, counted, identified and lengths and weights were taken from trout at each site to investigate differences in growth rates in addition to biomass estimates. Although electrofishing was attempted in reach 3 in 2014, downed powerlines in the creek from the railway restricted this data collection. Rather than electrofishing this portion of the creek, field observations and counts of fish within pools frequently from 2012-2014 provided evidence that fish were now able to pass above the culvert and provided a rough estimate of the size and count of fish present within each pool of reach 3.

Figure 3.7. Photo of workers electrofishing (left), photo of some fish collected (right).

3.2.5 Substrate

Pebble counts were performed to characterize channel substrate, estimate channel roughness, and assess sediment transport characteristics of the stream (Wolman 1954). A step-toe procedure was used. This method consisted of stretching a meter tape across a 100m transect of the stream, and collecting 100 particle samples at random. The procedure was completed for reach 1 and reach 2 in 2011. Samples were taken at approximately 0.2m increments in a zigzag pattern (see Figure 3.8) across the stream and were measured using a caliper type ruler. Since pebble counts were performed for stream characterization and comparison, pools, runs and riffles were sampled in the same proportions as they occur in the study reach (Wolman et al, 1964). Particles were tallied by using the size categories shown in Table 2.3, adapted from Wolman (1954).

Figure 3.8. Kama Creek Pebble count zig-zag path chosen for 100m's in reach 1 (left) and reach 2 (right).

3.2.6 Discharge / Level

The streamflow, or discharge, is the volume of water passing a single point in the stream over time. It is measured by determining the cross-sectional area and velocity (speed and direction) of the flowing water. The measurement is expressed in cubic metres per second (m^3/s).

The streamflow method was adapted from the United States Geological Survey (USGS). Streamflow was taken using a GEOPACKS propeller type manual FlowMeter, ruler and stopwatch timer (See Figure 3.9). Flow measurements were taken on a weekly basis in 2011, biweekly basis in 2012 and monthly in 2013 due to available time.

The procedure for flow data is as follows:

1. Clear channel of any leafy debris which would interfere with impeller. Do not alter shape or depth of stream channel.
2. String a tape measure across the stream at right angles to the flow and tie off on both sides of the stream. Measure and record the stream width from bank to bank
3. Start at the very edge of one bank and work your way across the stream, measuring depth with the ruler at 25 cm intervals

4. Set timer for 60 seconds and place impeller in water so it freely rotates. NOTE: Stand at least 1 foot away on the downstream side of the tape and hold the meter and rod next to the tape. Be sure you are standing far enough from the meter to ensure that the eddies around your boots are not interfering with the flow measurement.
5. Initiate timer and FlowMeter simultaneously. And measure flow (counts per 60 seconds) at the same 25cm intervals you measured depth.
6. Remove impeller and stop FlowMeter after the 60 second timer.
7. Note impeller count and record depth and width of channel in a field notebook.

Recorded flows (counts per 60 seconds) were later calculated into flow velocity using the following equation:

$V_{(m/s)} = (0.000854(C)) + 0.05$

Where C is impeller count per 60 seconds

And then further calculated into stream discharge (Q) using cross sectional area from stream channel measurements and calculated velocity V

$Q_{(m^3/s)} = (w * d) * V$

Where w is channel width, d is channel depth and V is flow velocity

Channel geometry and velocity were measured and used in conjunction with rainfall and water level data to assure accurate discharge estimates.

Level or stage data monitoring stations were established using Pressure sensor type Solinst water level gauges deployed at a few locations within the study area, level logger's 1 to 4, with two located downstream of the project in the old channel, one upstream of the project, reference reach logger 3, one within the project limits, located in the new channel, logger 4 and one barologger was deployed, which reads barometric air pressure and was used to compensate level data once uploaded to computer. The loggers were set to collect a depth measurement every hour and record the date and time of each measurement. These logger were uploaded to a laptop approximately once a month.

Figure 3.9 Flow meter being used to record velocity in Kama Creek.

3.2.6.1 Rating Curves and Hydrographs

A rating curve is the plot of the stage of the water versus the flow that the stream had at that stage (Buchanan and Sommers, 1969). A simple rating curve is used in circumstances when the flow is contained to a main channel section and can be assumed to be fairly steady and the bed of the stream does not significantly change. (How to Establish Stage Discharge Rating Curve, 1999). For this study flow was measured from inside the culvert at site 3 (See Figure 3.4), where the flow was considered to be steady.

Simple Rating curves were developed for site 3 in 2011, and updated discharge data was added in 2012 and 2013 using measured values of stage (m) from the level loggers in the stream and discharge (Q m^3 sec^{-1}) obtained using velocity-area method in the stream. Scatter plots were made for each rating curve with level on the x-axis and discharge on the y-axis. A polynomial regression was used for each curve to show the relationship between discharge and level/stage based on the simple rating curve.

The daily annual discharge was then calculated in Microsoft excel using the following polynomial type equation where:

$$Q = c_2 (hw + a)^2 + c_1(hw + a) - c_0$$

Q = discharge (m 3 /sec)

h = measured water level (m)

a = water level (m) corresponding to Q = 0

c_i = coefficients derived for the relationship corresponding to the station characteristics

This discharge data was plotted to create annual daily discharge hydrographs for site 3 in 2011, 2012 and 2013. The 2011 discharge hydrograph is show below in Figure 3.11 as an example. The maximum level for 2011 was 0.299m measured on October 18 with a corresponding discharge value of 0.092m^3/s.

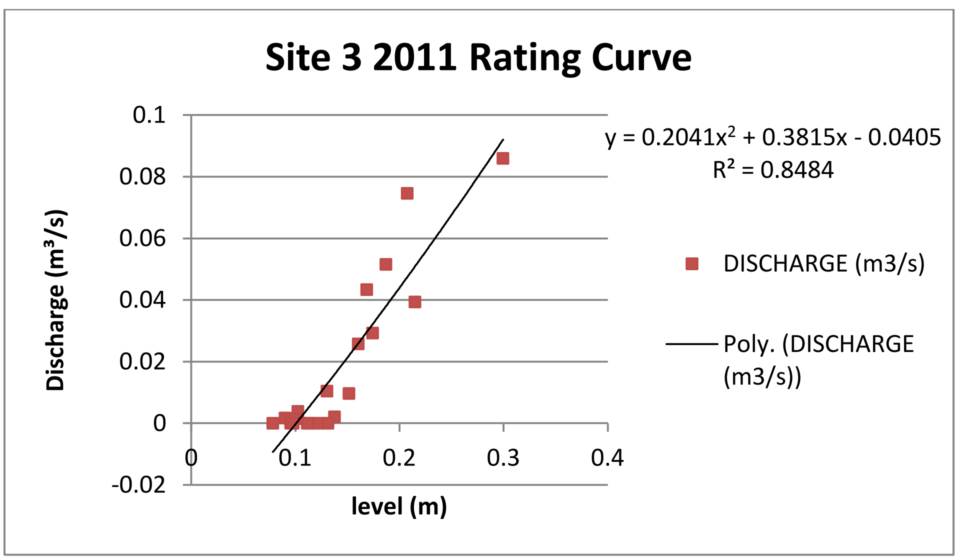


Figure 3.10. Rating curve produced for site 3, in 2011 using discharge and level data.

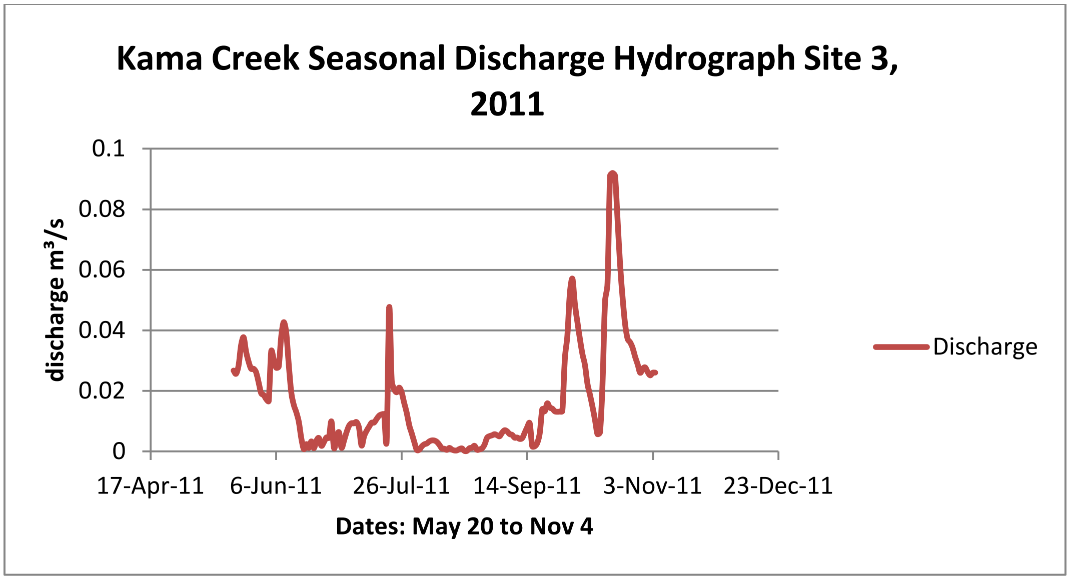


Figure 3.11. Seasonal Discharge Hydrograph for site 3 in 2011.

3.2.7 Precipitation

Precipitation was recorded for 2011 and 2012 using a Rainwise PortLog weather station on site at the mouth of Kama Creek (Figure 3.12). This PortLog weather station recorded wind speed, wind direction, temperature, humidity, dew point, barometer, rainfall and solar radiation every half hour and data was retrieved from the station using a laptop computer approximately once a month. Rainfall was the only parameter used from the station for this study. Precipitation data was used to plot against discharge and used to show annual discharge patterns of flow in relation to climate.

Figure 3.12 Weather station set up at Kama Creek near the delta of Lake Superior.

CHAPTER 4

RESULTS

The purpose of the research was to monitor the re-establishment of Kama Creek pre and post restoration. The objectives were to establish baseline conditions prior to creek restoration; compare baseline conditions to post-restoration conditions, and; to make recommendations for long-term monitoring of ecosystem improvements in Kama Creek. The survey included fish population surveys, water quality sampling, measuring stream discharge and conducting a habitat assessment protocol of the restored and pre-restored creek. The primary field data was conducted over 2 years between May and November of 2011 and 2012. Additional discharge data, fish survey data, water temperature data and habitat assessment observations were collected again in 2013 and 2014 to further support the results of the two primary data collection years.

Prior to restoration activities, the focus of the baseline data was placed on reach 1(site 1) in 2011. This is the portion of the stream that was diverted in the 1960s and where fish passage was cut off at the railway culvert (See Figure 3.2). A second reach, reach 3 (site 3), was also established above the culvert to determine the presence of fish before and after restoration, and to act as a reference for discharge measurements for all years of the survey. Post restoration data (2012 and 2013) in the restored portion of the creek below the culvert was established as reach 2 (site 2).

4.1 Water Quality Parameters

Water quality was monitored to identify if Kama Creek (pre and post restoration) was meeting basic guidelines for the protection of aquatic life and to identify any trends or concerns with water quality after construction activities. Table 4.1 is a summary of the water quality parameters collected in 2011 and 2012 as compared to standards and guidelines. As shown in Table 4.1 below, all water quality parameters were within CEQG standards or other brook trout habitat suitability standards with the exception of total dissolved solids, conductivity and for 2012 dissolved oxygen (10.3 mg/L), however, only slightly exceeded optimal range for aquatic life but still falls within the guideline of about 5mg/L (9.5mg/L maximum range)

Table 4.1 Water Quality Parameters and Guidelines

Water Quality Parameter	2011 Mean Value	2012 Mean Value	Water Quality Guidelines or standard	References
pH	7.8	7.6	Ph 6.5-9.0 Most productive 6.5-8.5	Habitat Suitability Index Models: Brook Trout (Raleigh, R.F. 1982)
DO (mg/L)	9.38	10.3	≥ 5.0 mg/L Most productive 6.5-9.5mg/L	Canadian Environmental Water Quality Guidelines (CEQG), CCREM 1987, AEP 1997, and Truelson 1997), (Kerr, 2000)
Conductivity (µS)	211.6	565.1	Desirable range 100-2,000 µS/cm	Stone and Thomforde (2004)
TDS (ppm)	103.7	279.9	> 20 ppm but < 50ppm	Habitat Suitability Index Models: Brook Trout (Raleigh, R.F. 1982), (Kerr, 2000)

Note: Adapted from (Raleigh, R.F. 1982), (Kerr, 2000), (CEQG), (CCREM, 1987), Stone and Thomforde (2004), (Truelson, 1997)

4.1.1 Total Dissolved Solids (TDS) and Conductivity (μS/cm) Parameters

Total dissolved solids (TDS) is a measure of the amount of particulate solids that are in solution and is expressed in (mg/L). As shown in Table 4.2, total dissolved solids (TDS) and conductivity appear to show similar trends, as the measure of TDS is derived from the conductivity of the water column. Conductivity also can be used to give a rough estimate of the total amount of dissolved solids (TDS) in water. Typically, the TDS value in mg/l is about half of the Conductivity (μS/cm) Stone and Thomforde (2004). Small size in trout has been attributed to low TDS values less than 20 ppm, (Lennon 1967). Table 4.2 shows that site 1 (mean 109.3 ppm) and reference site 3 (mean 110.9 ppm) had the lowest average values of TDS and conductivity in 2011 and site 3 (mean 302.9 ppm) and 2 (mean 278.6 ppm) had the highest values in 2012. The minimum value of total dissolved solids increased from a min of 16ppm to a min of 249ppm from 2011 and 2012. The reasons for the high TDS values is not known but the reason for the jump in values from 2011 to 2012 is likely due to construction activities in 2012 that caused excess minerals of rocks and soil disturbance. TDS values in lakes and streams are typically found to be in the range of 50 to 250ppm. In areas of especially hard water or high salinity, TDS values may be as high as 500ppm.The TDS concentration in a body of water is affected by many different factors. It is normal for streams to dissolve and accumulate fairly high concentrations of ions from the minerals in the rocks and soils over which they flow. If these deposits contain salts (sodium chloride or potassium chloride) or limestone (calcium carbonate), then significant concentrations of Na^+, K^+, Cl^- will result. If TDS levels are high, especially due to dissolved salts, many forms of aquatic life can be affected. So TDS would be an important parameter to monitor closely in the future (Johnson et al. 2015).

4.1.2 pH

Site 1 and 3 had the highest average pH value of 7.8 in 2011 and in 2012 values were 7.4 and 7.6 for site 3 and site 2 respectively over the course of the testing period. Table 4.2 shows that site 3 had the lowest pH value of 7 in 2011 over the testing period, and the highest range of values, 7-8.6. Regardless of the slight change, these values fall within the most productive range of the guidelines in Table 4.1.

4.1.3 Dissolved Oxygen and Temperature

The ability of water to hold oxygen in solution is inversely proportional to the temperature of the water. For example, the cooler the water temperature, the more dissolved oxygen it can hold. As shown in Table 4.2, dissolved oxygen was lowest at site 1 in 2011 with an average of 9.3mg/L and a temperature of 10.9°C. In 2012, site 2 had a mean dissolved oxygen reading of 10.9mg/L with a mean temperature of 9.5°C. This trend occurs at all sites; as temperature decreases the amount of dissolved oxygen increases, shown in Table 4.2. The range of DO values is 3.31mg/L in 2011 to 14mg/L in 2012. In (Table 4.1) the DO standard should be >5mg/l according to the Canadian Environmental Quality Guidelines and the optimal range is 6.5-9.5mg/L according to Kerr (2000).

Table 4.2 Water quality parameter per site[1] for Kama Creek, Nipigon, Ontario in 2011 and 2012

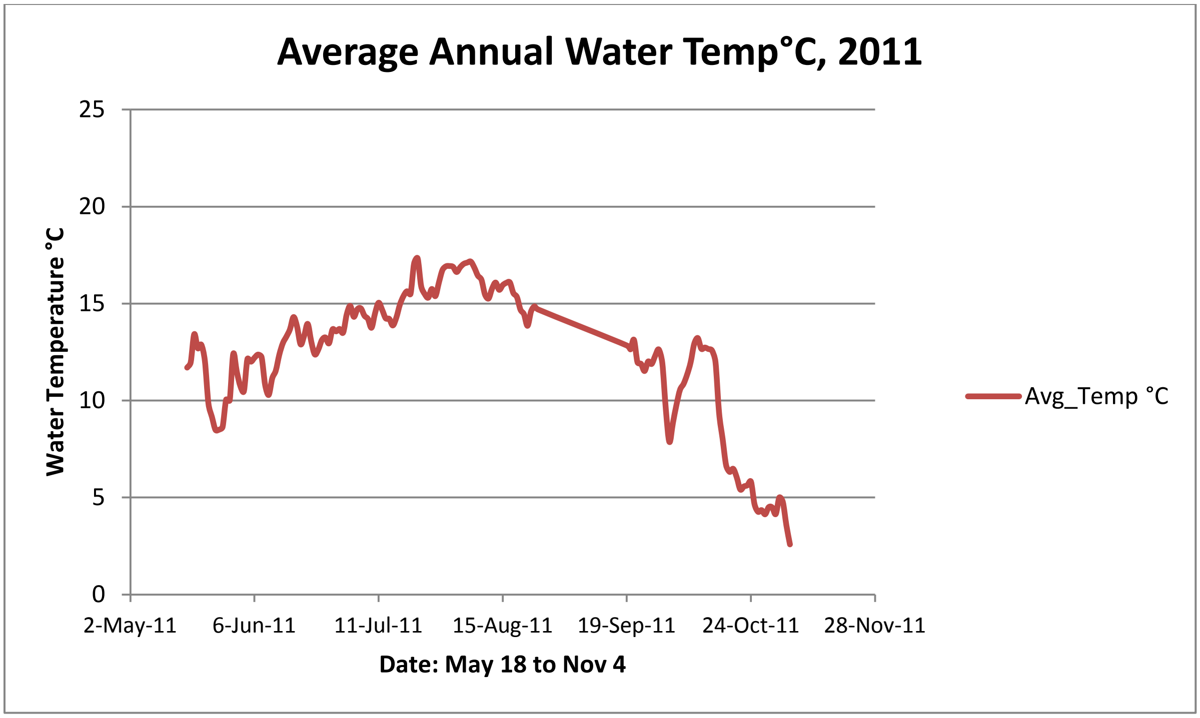
Total Dissolved Solids (ppm)		Min	Max	Range	Median	Mean	Std. Dev.	Variance
	2011							
Site 1		15	259.5	244.5	57.3	109.3	109.8	12066.3
Site 3		16	360	344	54.5	110.9	114.8	13188.9
	2012							
Site 3		249	321.5	72.5	317	302.9	36.5	1332.9

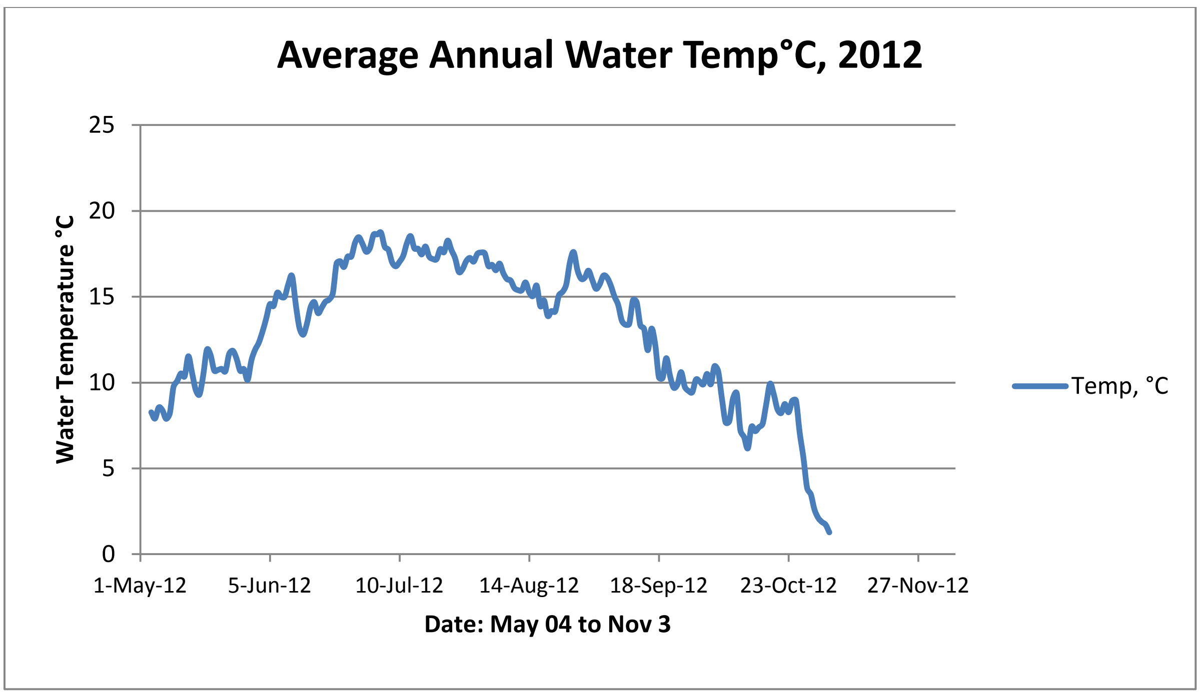
		Min	Max	Range	Median	Mean	Std. Dev.	Variance
Site 2		201.5	328.5	127	276	278.6	45.9	2102.8
Conductivity (µS/cm)		Min	Max	Range	Median	Mean	Std. Dev.	Variance
	2011							
Site 1		30	519	489	114.8	221.4	229.2	52551.1
Site 3		31	767	736	108	225.7	238.9	57079.5
	2012							
Site 3		500.5	672	171.5	640.5	613.4	77.5	6013.7
Site 2		403	654.5	251.5	553	562.4	95.9	9197.5
pH		Min	Max	Range	Median	Mean	Std. Dev.	Variance
	2011							
Site 1		7.3	8.2	0.9	7.9	7.8	0.3	0.1
Site 3		7	8.6	1.6	7.9	7.8	0.4	0.2
	2012							
Site 3		7.1	7.4	0.3	7.4	7.4	0.3	0.1
Site 2		7.8	8.1	0.3	7.5	7.6	0.4	0.2
Temperature (°C)		Min	Max	Range	Median	Mean	Std. Dev.	Variance
	2011							
Site 1		3	16.7	13.7	10.6	10.9	5.3	28.5
Site 3		3.2	17.4	14.2	10.5	10.4	5.5	30.4
	2012							
Site 3		7.7	12.9	5.2	9.2	9.3	3.2	9.9
Site 2		5.2	15.3	10.1	10.7	9.5	4.3	18.5
Dissolved Oxygen (mg/L)		Min	Max	Range	Median	Mean	Std. Dev.	Variance
	2011							
Site 1		3.31	11.8	8.5	9.3	9.2	2.5	6.3
Site 3		8.1	12.6	4.5	9.6	9.4	2.6	6.7
	2012							
Site 3		8.1	11.4	3.3	11.3	10.7	1.8	3.3
Site 2		11.8	14.0	2.2	11.5	10.9	2.4	6

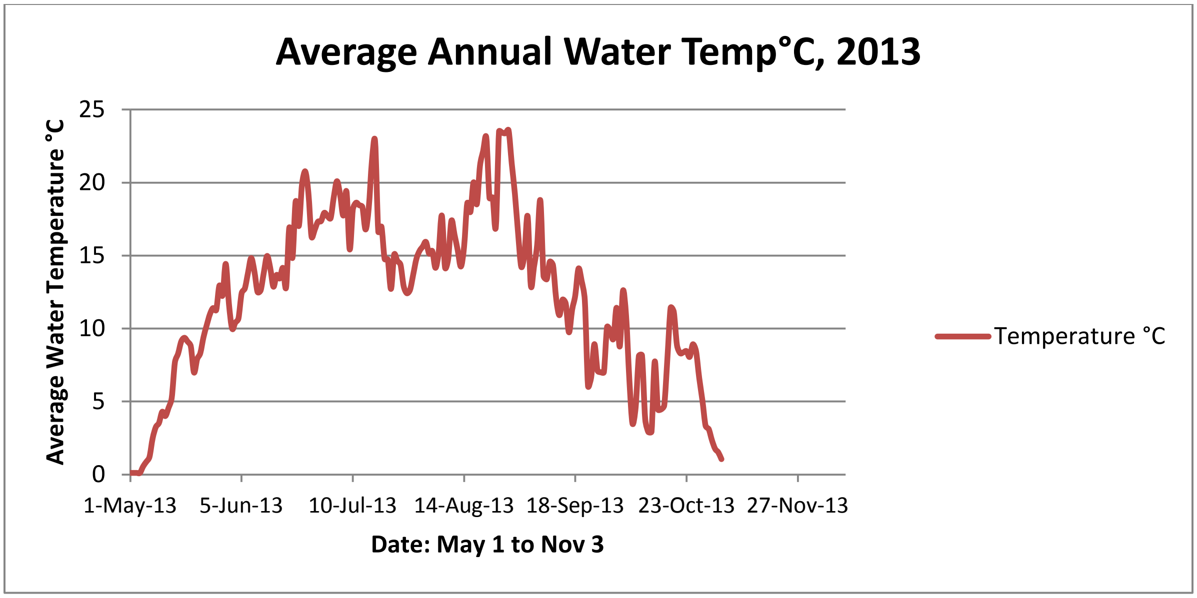
[1] [Site 1: Old Straightened Channel] [Site 3: Reference Reach above the culvert] [Site 2: Newly Restored Channel]

4.2 Water Temperature

Temperature plays a very important role in fish growth. Water temperature that is too high or too low will decrease growth due to metabolic demands. Average spring/summer/fall water temperatures for Kama Creek were plotted for 2011, 2012, 2013 and 2014 and shown in Figure 4.2 below. General trends in the curve of the data are similar for all years. Spring average temperatures were 11.6°C, 11.9°C, 9.1°C and 9.2°C for 2011 to 2014 respectively. Summer temperatures increased to15.1°C, 16.2°C, 16.7°C and 13.0°C for 2011 to 2014 and fall average temperatures decreased to 8.8°C, 7.8, 6.9, 5.1 for 2011 to 2014 respectively. Average daily temperature overall, decreased from 12.3°C to 10.3°C from 2011 to 2014, and the range of daily maximum temperatures narrowed by 4°C. What was thought to be a groundwater seep was located within the newly restored channel, where additional photos were taken and temperatures were measured (Figure 4.2a). The lowest temperature recorded during summer months at this seep was 11.8°C. This seep could have been standing water caused by a perched aquifer and the thick lacustrine clay layer found in the pools of the new channel when it was excavated, prevented inflow of this water (See Figure 4.2b,c).


Average Annual Water Temp°C, 2011
Water Temperature °C
25
20
15
10
5
0
2-May-11
6-Jun-11
11-Jul-11
15-Aug-11
19-Sep-11
24-Oct-11
28-Nov-11
Date: May 18 to Nov 4
Avg_Temp °C


Average Annual Water Temp°C, 2012
Water Temperature °C
25
20
15
10
5
0
1-May-12
5-Jun-12
10-Jul-12
14-Aug-12
18-Sep-12
23-Oct-12
27-Nov-12
Date: May 04 to Nov 3
Temp, °C



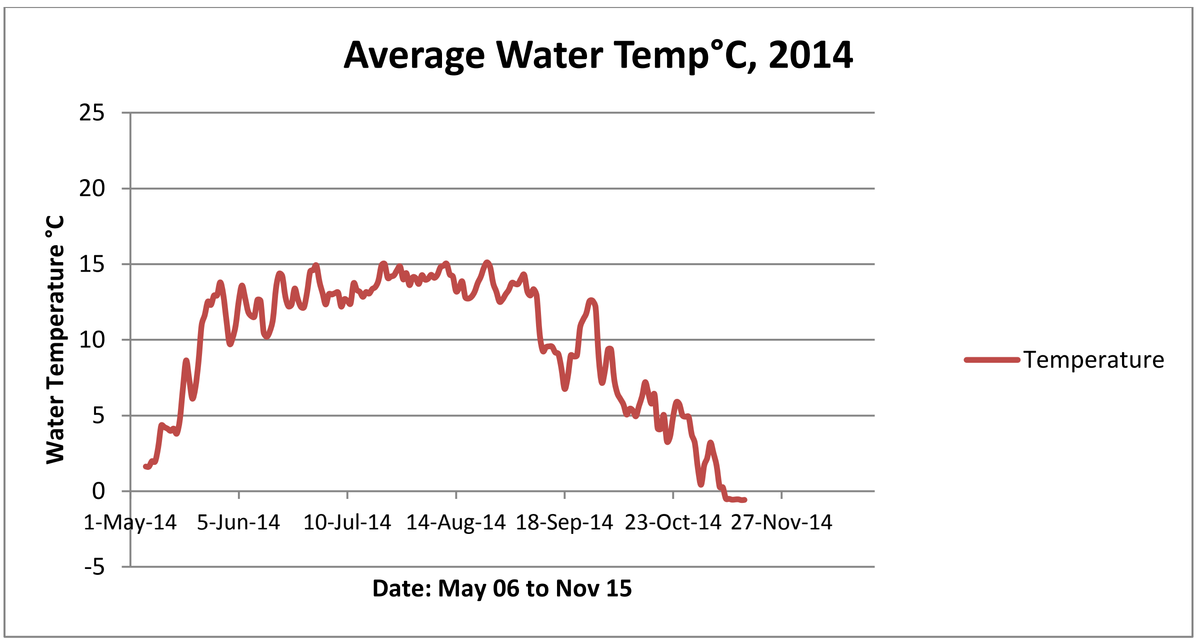


Figure 4.2 Average annual water temperature plotted for a) 2011, b) 2012, c) 2013 and d) 2014, data collected from sites 1, 2 and 3.

Figure 4.2a Groundwater seep located on the bank of newly restored reach of Kama Creek.

Figure 4.2b and c. Photos of clay bottom found when excavating reach 2 of Kama Creek. Arrow points to thick clay layer in pool of new channel (left). On the right, section of clay showing layering.

4.3 Habitat Assessment

Habitat Parameters were measured in the Kama Creek for reach 1, (old straightened channel) in the summer of 2011. Reach 2 (newly restored channel) assessment was done in 2012 directly after restoration and in 2014.

4.3.1 Epifaunal Substrate/Available Cover

In 2011, reach 1 showed an optimal amount of available cover with many fallen logs and large woody debris (Figure 4.3a). It was given a rating of 20 for most optimal epifaunal substrate and available cover (Table 4.1) because greater than 50% of the substrate was favorable for epifaunal colonization and fish cover. In 2012 the newly restored channel (reach 2) was rated as poor conditions for available cover. This was due to a lack of cover directly after construction (Figure 4.3b). In 2014, reach 2 established a variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs and branches, and undercut banks. These features provide refugia, feeding sites, and sites for spawning and nursery from the esablishment of aquatic macrofauna (Figure 4.3c). These factors increased the rating to 11 at the low end of suboptimal habitat.

Score

Reach 1. 2011
Reach 2. 2012
Reach 2. 2014
Reach 2. No changes from 2012 to 2014

Table 4.3 Visually Based Habitat Assessment Epifaunal Substrate/Available Cover

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1.Epifaunal Substrate/	Greater than 50% of substrate favorable for epifaunal colonization and	30-50% for low gradient streams) mix of stable habitat; well-suited for	20-40% (10-30% for low gradient streams) mix of	Less than 20% (10% for low gradient streams) stable

Available Cover	fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale)	stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.3a. Reach 1 Showing optimal cover in 2011.

Figure 4.3b. Reach 2 2012 showing minimal cover

Figure 4.3c. Reach 2 in 2014 showing improvements in cover compared to 2012.

4.3.2 Pool Substrate Characterization

Even though the old channel consisted of a good mixture of substrate materials with gravel and firm sand it was ranked on the lower end of an optimal condition (See Table 4.4) due to the fact that there was little to no root mats and submerged vegetation (Figure 4.4a). The new channel in 2012 was rated on the lower end of a marginal condition because the majority of the substrate was mud or clay with little or no root mat and no submerged vegetation. In 2014 reach 2 had improved slightly because of more vegetation growth (See Figure 4.4c) and was ranked on the higher end of the marginal condition.

Score	
Green	Reach 1. 2011
Red	Reach 2. 2012
Blue	Reach 2. 2014
Purple	Reach 2. No changes from 2012 to 2014

Table 4.4. Pool Substrate Characterization

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation	Hard-pan clay or bedrock; no root mat or submerged vegetation.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.4a. Reach 1 in 2011 showing optimal substrate. Figure 4.4b. Reach 2 in 2012 showing poor Substrate with mud and clay dominant And no submerged vegetation.

Figure 4.4c. Reach 2 in 2014 showing slight improvements in pool substrate characterization.

4.3.2.1 Substrate Type and Size

Pebble counts were performed for Reach 1 and Reach 3 (above the culvert) in 2011, according to Wolman (1954). Reach 1 in 2011 shows a high average percent of small gravel (Figure 4.5) (Table 4.5). Plotted by reach, little variability among reaches is observed indicating the overall average percentage is representative of each tributary. A pebble count was only performed for reach 1 (the old channel) and reach 3 (the channel above the culvert) in 2011 because the restored channel in 2012 could be estimated from the design specifications and the known percentages of cobble used in the construction activities. Photos were taken (Figure 4.6) and visual observations were made on the newly restored channel (reach 2) to ensure these design specifications of pebble to boulder size are consistent throughout the newly restored channel. The proposed substrate sizes in the original design, for the new channel consisted of very coarse-grained particles with the following dimensions and mix proportions:

30% 600mm round stone (boulder)
40% 200mm round stone (boulder)
30% native material (mostly sand and gravel with some small cobbles)

However, Figure 4.6a is a more accurate diagram, from the design, of substrate size actually used in the stream. The 600mm boulders were not used.

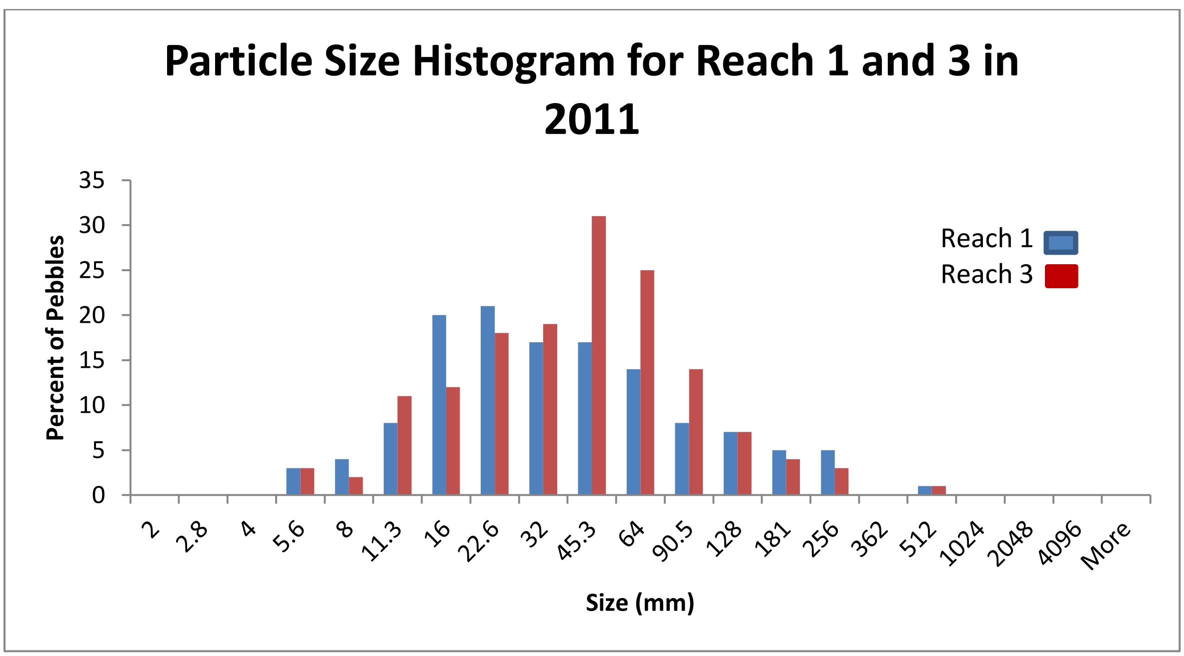


Figure 4.5. Historgram for Pebble Count performed on Kama Creek reach 1 and 3 in 2011.

Table 4.5. Substrate type and Size (Wentworth scale)

Substrate Type	Size Category
mud/silt	fine and smooth, not gritty
sand	0.2 - 2 mm (feels gritty)
gravels	2 - 60 mm
small cobbles	60 - 120 mm
large cobbles	120 - 250 mm
boulder	> 250 mm
bock	bed of stream is comprised of solid rock
constructed	concrete

Note: Adapted from http://limnology.wisc.edu/courses/zoo548/Wolman%20Pebble%20Count.pdf

Figure 4.6 Photos of the restored channel showing substrate size and type present.

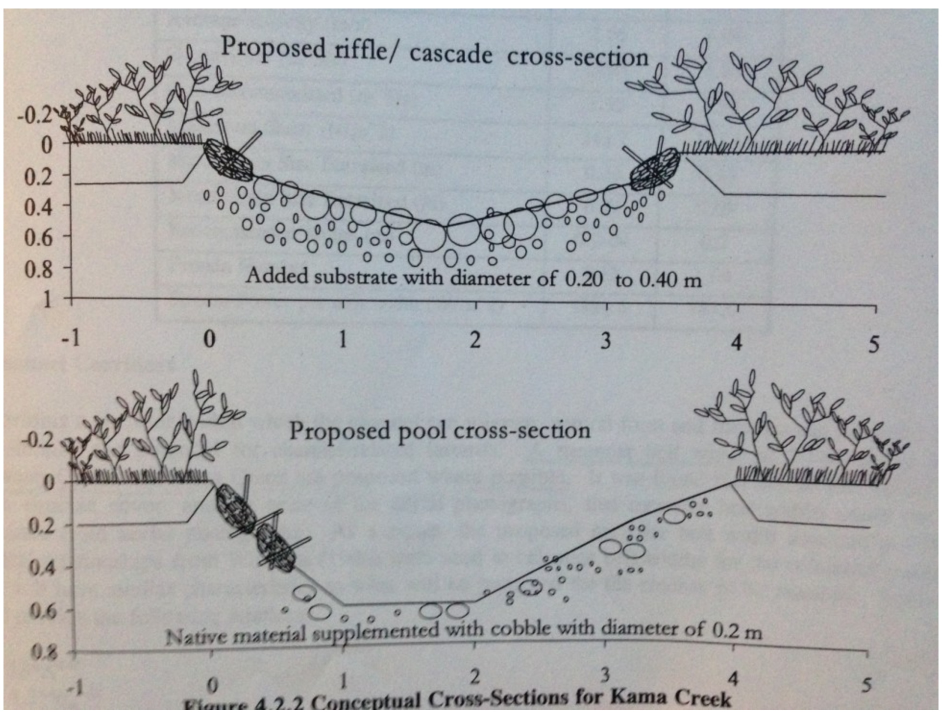


Figure 4.6a. A cross-section of the riffle/pool used in restoring Kama Creek with sizes of substrate shown.

Particle size distribution curves, comparing reach 1 and reach 3 data, are illustrated in Figure 4.7. D50 is the particle size that 50% of the samples are equal to or smaller than. D50 for Reach 1 was calculated to be 24.3mm and D50 for Reach 2 (above the culvert) was 51.6mm.

This means that 50% of the substrate particles are within 13–128 mm preferred (movable) spawning substrate size range for salmon and trout species (Bjornn and Reiser, 1991).

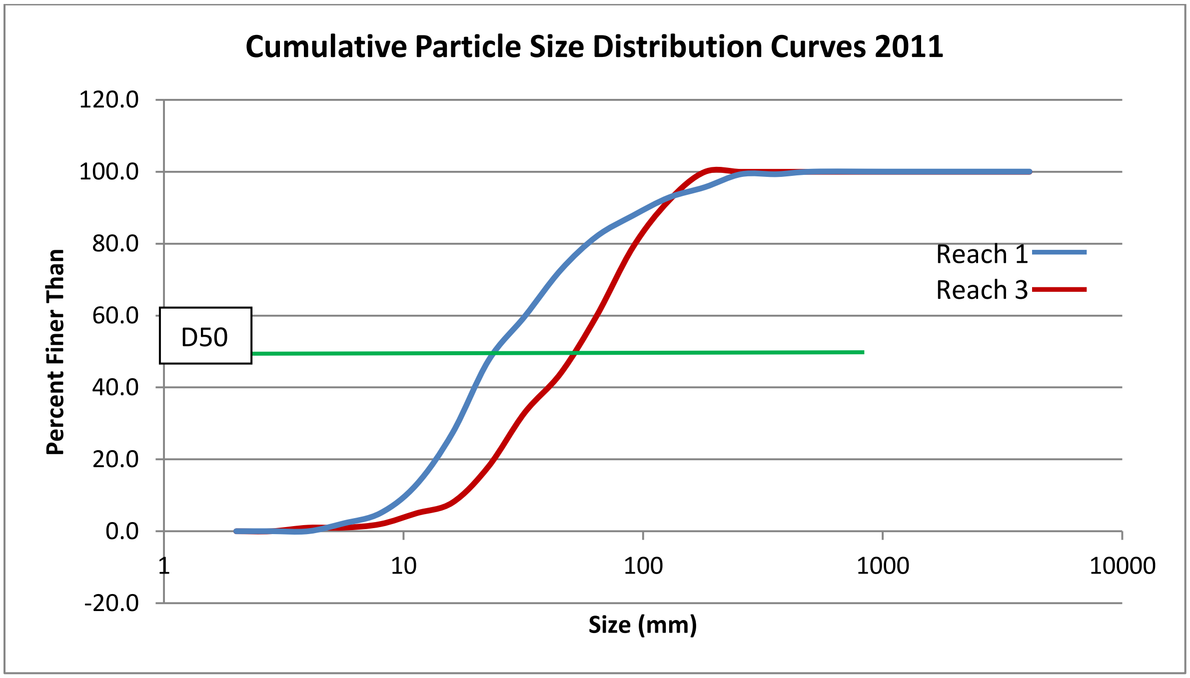


Figure 4.7. The fraction of number of particles with diameter less than or equal to a given diameter.

4.3.3 Pool Variability

Because the old channel was constructed as a drainage tributary, it had few shallow/small pools and one large pool. As a result it received a low ranking in the marginal condition category (Figure 4.8a). The newly restored channel was designed to have optimal pool variability with an even mix of large deep pools and small-deep, small-shallow pools. This did not change noticeably from 2012 and 2014 and was ranked at the lower end of the optimal condition for both years. Reach 2 was not ranked at the high end of the optimal condition (See Table 4.6) because although an even mix of large and small pools existed, sediment deposition has caused the large pool to fill in and this situation will probably deteriorate in the future as the remaining pools are filled with sediment.

Score

- Reach 1. 2011
- Reach 2. 2012
- Reach 2. 2014
- Reach 2. No changes from 2012 to 2014

Table 4.6. Pool Variability

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools	Majority of pools small-shallow or pools absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.8a. Marginal in the old channel in 2011 with few shallow pools present.

Figure 4.8b. Reach 3, shows a mixture of large deep small shallow and small-deep pools.

4.3.4 Sediment Deposition

Sediment deposition in reach 1 (2011) was present but minimal (See Figure 4.9a). Since the channel was straightened in the 1960's little enlargement of islands or point bars formed and there was minimal effect of the stream bottom by sediment deposition. Deposition occurs from large-scale movement of sediment, and because of erosion in the newly restored channel following construction. Sediment deposition in reach 2 from 2012 to 2014 caused a decreased within the marginal category from a score of 10 to a lower score of 6 (see Figures 4.9b and 4.9c).

Score

Reach 1. 2011
Reach 2. 2012
Reach 2. 2014
Reach 2. No changes from 2012 to 2014

Table 4.7 Sediment Deposition

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for low gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low- gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.9a. Arrow shows sediment deposition in old channel in 2011

Figure 4.9b. Little deposition in 2012 as channel was freshly dug

Figure 4.9c. Reach 2 in 2014 starting to show sediment deposition

4.3.5 Channel Flow Status

Figure 4.10a is a common and visible example that the water in the old channel only fills approximately 50% of the available channel. As a result of this observation throughout 2011, the flow status for Reach 1 is ranked as marginal. In 2012 and 2014 the newly restored channel shows a suboptimal channel flow status as water fills approximately 75% of the channel, and a minimal amount of the channel substrate is exposed. This may decrease over time as erosion occurs and sediment is deposited. The photos (Figures 4.10a and b) represent conditions of the stream on the days that the habitat assessment was performed (summer of 2012 and summer of 2014). Seasonal changes will be a large factor in rating the flow status and it is difficult to rate this condition as water would fill the channel in the spring and fall when higher flows occur and summer low flows may cause the channel to have very little water. Climate will also affect the rating of channel flow status as one year may have high annual precipitation and another year may be in drought conditions.

Score

Reach 1. 2011
Reach 2. 2012
Reach 2. 2014
Reach 2. No changes from 2012 to 2014

Table 4.8. Channel Flow Status

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.10a. 2011 Marginal channel flow status

Figure 4.10b. 2014 suboptimal channel flow status

4.3.6 Channel Alteration

Because the old channel (Reach 1) was straightened in the 1960s to prevent flooding of the rail line the channelization was extensive (See Figure 3.2). However, over time, the stream did form its own natural bends and meanders and can be ranked within the marginal condition (as opposed to poor condition in the 1960s). The new channel was restored to mimic the natural bends and meanders of the historic natural river bed that existed prior to the 1960's, and as a result of this design, (See Figure 3.4) was intended to be optimal in the channel alteration category. However, some channelization is present post construction, decreasing the overall ranking of the newly restored channel to suboptimal (See Table 4.9).

Score

- Reach 1. 2011
- Reach 2. 2012
- Reach 2. 2014
- Reach 2. No changes from 2012 to 2014

Table 4.9. Channel Alteration

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

4.3.7 Frequency of Riffles (or Bends)

Figure 4.12a is an example of the old channel which had a relatively frequent occurrence of riffles and was ranked on the lower end of an optimal condition. The newly restored channel (See Figure 4.12b) was also ranked optimal with a high frequency of riffles as the design intended (7 in total). It was ranked higher than the old channel as proper sized boulders are in place for habitat. Figure 4.12c is a detail of the typical riffle/pool sequence that was used in the design of the restored channel.

Score

Reach 1. 2011
Reach 2. 2012
Reach 2. 2014
Reach 2. No changes from 2012 to 2014

Table 4.10. Frequency of Riffles (or bends)

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
7a. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.12a. Occasional riffles present in 2011.

Figure 4.12b. Optimal occurrence of riffles in new channel.

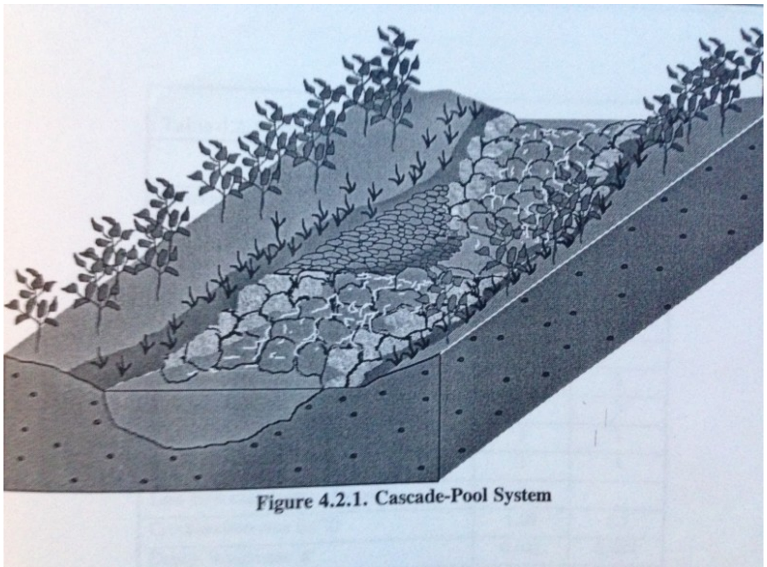


Figure 4.12c Riffle pool sequence used in the Kama Creek restoration design.

4.3.8 Channel Sinuosity

Due to geological control, gradients are steep and highly variable along the Kama Creek system (Clearwater and Kama Creek Study and Restoration, MNR). The steep grade likely accounts for the low channel sinuosity seen in Kama reach 1 which ranked marginal for channel sinuosity (See Table 4.11). The bends in the stream only increase the length of the stream by 1 or 2 times (See Figure 4.13a). The newly restored channel has a high degree of sinuosity and ranked optimal because the bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. This feature is a result of the design which followed the natural channel which existed pre 1960s. This natural meander pattern is shown in Figure 4.13b.

Score

- Reach 1. 2011
- Reach 2. 2012
- Reach 2. 2014
- Reach 2. No changes from 2012 to 2014

Table 4.11. Channel Sinuosity

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
7b. Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note - channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.)	The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line.	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line.	Channel straight; waterway has been channelized for a long distance.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.13b. Old channel dredged in the 1960 for the railway.

Figure 4.13b. New channel in 2014, constructed in pre 1960's 'natural' channel.

4.3.9 Bank Stability (condition of banks)

Reach 1 has steep banks which are more likely to collapse and suffer from erosion than are gently sloping banks, and are therefore considered to be unstable (See Table 4.12). Though the banks of reach 1 are very steep the channel has not suffered severely from erosion as the stream has stabilized so it was rated in the suboptimal condition category. Figures 4.14b and 4.14c show that erosion of banks was minimal in 2012 along the restored channel, but has increased in 2014 as more water flowed through the newly constructed stream.

Score

- Reach 1. 2011
- Reach 2. 2012
- Reach 2. 2014
- Reach 2. No changes from 2012 to 2014

Table 4.12 Bank Stability

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
8. Bank Stability	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30- 60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.14a. 2011 old channel showing steep eroded banks.

Figure 4.14b. 2012 new channel showing little erosion on banks.

Figure 4.14c. 2014 new channel showing erosion of banks.

4.3.10 Bank Vegetation Protection

Banks that have full, natural plant growth are better for fish and macroinvertebrates than are banks without vegetative protection or those with concrete or riprap on their banks. Reach 1 was ranked optimal for vegetation protection as the stream bank surface and riparian zone is covered by native vegetation, as seen in Figure 4.15a. Reach 2 was ranked suboptimal in 2012 as it was a newly restored channel and did not have time for adequate plants to grow and take root immediately after construction (See Table 4.13 and Figure 4.15b). However, the vegetation protection has improved drastically from 2012 to 2014 to an optimal condition in Table 4.13 (also see Figures 4.15c and d).

Score

- Reach 1. 2011
- Reach 2. 2012
- Reach 2. 2014
- Reach 2. No changes from 2012 to 2014

Table 4.13. Vegetation Protection

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
9. Vegetative Protection	More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well- represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.15a. Photo shows optimal vegetation in 2011. Figure 4.15b. In 2012 vegetation not yet grown.

Figure 4.15c. and d. By 2014 vegetation has already grown thick along bank of new channel.

4.3.11 Riparian Vegetation Zone Width

The vegetative zone serves as a buffer to pollutants entering a stream from runoff, controls erosion, and provides habitat and nutrient input into the stream. The Riparian zone width for reach 1 is ranked marginal in Table 4.14 as there are cottages directly to the left bank of the channel but has little human impact (Figure 4.16a). The width of riparian vegetation is approximately 6 meters on the left bank and only slightly more on the right bank. Reach 2 (Figure 4.16b) is ranked suboptimal in Table 4.14 for its riparian vegetation zone width (12-18 meters) and because it has not been impacted, or only minimally impacted, post restoration.

Score

Reach 1. 2011
Reach 2. 2012
Reach 2. 2014
Reach 2. No changes from 2012 to 2014

Table 4.14. Riparian Vegetative Zone Width

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
10. Riparian Vegetative	Width of riparian zone >18 meters; human activities (i.e., parking lots,	Width of riparian zone 12- 18 meters; human activities have impacted	Width of riparian zone 6- 12 meters; human activities	Width of riparian zone <6 meters: little or no riparian

Zone Width	roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	zone only minimally.	have impacted zone a great deal.	vegetation due to human activities.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Note: adapted from http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers.

Figure 4.16a. Cabins along the shore are affecting the riparian zone.

Figure 4.16b. Wide riparian zone with minimal human human activity or impact.

The purpose of the individual condition categories of the habitat assessment protocol are designed to be added together for an overall assessment score. This score is shown in Table 4.15 where Reach 1 received a total score of 0.71 which falls in the suboptimal condition, Reach 2s total score was 0.72 in 2012 and increased to 0.75 both also in the suboptimal condition category.

Table 4.15 Condition Category Total Scoring for Kama Creek Reach 1 and Reach 2

Condition Category	2011	2012	2014
Optimal (16-20), Suboptimal (11-15) Marginal (6-10) Poor (0-5)			

Epifaunal Substrate/ Available Cover	20	5	11
Pool Substrate Characterization	16	6	10
Pool Variability	6	16	16
Sediment Deposition	11	10	6
Channel Flow Status	10	11	11
Channel Alteration	9	15	15
Frequency of Riffles (or Bends)	16	20	20
Channel Sinuosity	10	20	20
Bank Stability (condition of banks)	15	16	12
Bank Vegetation Protection	18	12	16
Riparian Vegetation Zone Width	10	12	12
Total Score	141 (141/200 = 0.71)	143 (143/200 = 0.72)	149 (149/200 = 0.75)

Total Score	Condition
0.85 – 1.00	Optimal/Reference
0.65 – 0.84	Suboptimal
0.35 – 0.64	Marginal
0.00 – 0.34	Poor

Note: Adapted from Phase 2 Stream Geomorphic Assessment Vermont Agency of Natural Resources May, 2007

4.4 Fish Survey

Fisheries data was collected by electrofishing a portion of reach 1 and 3 (above the culvert) on June 2nd of 2011 before the restoration activities occurred. Electrofishing again occurred in reach 2 (restored channel) on July 23 of 2014, but because of dangerous conditions in reach 3 that now existed as a result of downed power lines from the rail line, fish data could not be collected via electrofishing. Instead, fish survey data in reach 3 (above the culvert post remediation) were achieved by visual observations of fish counts in pools. On June 2nd of 2011 discharge was 0.0176 m^3/s for reach 1 and 0.0170 m^3/s in reach 3. The average depths measured on June 2nd were 0.079 m at logger 1 in reach 1 and 0.141 m for logger 3 in reach 3. On July 23 of 2014, in reach 2 the discharge was 0.0193 m^3/s and the average depth in reach 2 was 0.208 m.

Table 4.16 shows that 14 Brook trout and 45 rainbow trout were found downstream the culvert prior to restoration. No fish were found above the culvert as a result of the impasse created by the perched culvert in 2011. On visual assessment a range of fish species (trout, salmon and white suckers) has been observed above the remediated culvert in the spring/summer/fall of 2012 and 2013 (Figure 4.18). In 2014, 14 rainbow trout were captured and lengths were taken, however, no brook trout were captured in the 2014 sample. Table 4.17 summarizes the different fish species found in reach 1 and reach 2 in 2011 and 2014. Of interest are the high numbers of coho salmon found in both old and restored channel.

Figure 4.17. Brook trout and rainbow trout collected during electrofishing.

Table 4.16. Total biomass for Brook Trout and Rainbow trout collected 2011 and 2014 in the Kama Creek, reach 1 and 3, below the culvert.

Date	June 2011		July 2014	
Stream Section	Reach 1. Below the culvert (old channel)		Reach 2. Below the culvert (newly restored channel)	
Species	Brook Trout	Rainbow Trout	Brook Trout	Rainbow Trout
Total Catch	14	45	n/a	14
Length Range(mm)	28-163	71-93		90-102
Average Length (mm)	61	81		97

Table 4.17. Other fish species collected in 2011 and 2014 in Reach 1.

Date	June/August 2011 Reach 1 (old channel)	July 2014 Reach 2 (newly restored channel)
Species	Total Catch	
Mottled sculpin	6	37
Coho salmon	62	68
Lake chub	9	3
Longnose dace	10	6
Brook stickleback	14	n/a
White sucker	1	n/a

Figure 4.18. Rainbow Trout spotted above the culvert in Reach 3 of Kama Creek in May of 2013, and a common white sucker at culvert in new channel. Photo taken May 27, 2013.

4.5 Discharge/Level and Flow

Stream flow is a critical habitat parameter that determines quality of trout habitat. Flow measurements were taken at all sites throughout the study but reference Reach 3 data is used to represent the Kama Creek overall discharge and velocity. The Kama Creek had a relatively stable streamflow from May to November each year with higher flows in the spring and fall and almost no movement in the summer when the stream was dry with very little to no water in it.

Average flows for all seasons in 2011, 2012 and 2013, with the exception of summer 2013 where flow measurements were not taken, are shown in Table 4.18 below. Max flow values for spring summer and fall, are high and out of the optimal range for brook trout (see Table 4.19) for 2012. Average spring/summer/fall flow for 2011 was 0.187m/s and 0.2161m/s for 2012. Average summer flow or base flow for 2011 was 0.28m/s which is slightly high for brook trout requirements but in 2012 it was 0.08m/s and this is within the optimal range. It is interesting to note that average velocity in the summer of 2011 (0.21m/s) was higher than the average spring velocity of 0.189m/s in 2011. This is in contrast with 2012 where the average summer velocity is 0.077m/s and 0.275m/s in the spring. Since fish surveys were taken in the summer of 2011 this could affect the electrofishing survey results but because no velocity was taken for 2014 this is difficult to say.

Table 4.18 Flow Velocity for Kama Creek per season and year

	2011		2012		2013	
Velocity (m/s)	Average	Min-max range	Average	Min-max range	Average	Min-max range
Spring	0.1887	<0.05 – 0.6478	0.2746	<0.05 – 0.5282	0.6513	<0.05 – 1.2388
Summer	0.2088	<0.05 – 0.6009	0.0766	<0.05 - 0.1388	n/a	n/a
Fall	0.2332	<0.05 – 0.6376	0.0746	<0.05 – 0.1012	1.2001	<0.05 – 1.9288
Avg Spring/ Summer/Fall Flow	0.2252		0.2161		n/a	

Note: summer flow not recorded in 2013

Table 4.19 Optimal Flow for Brook Trout

Optimal flow for brook trout	Reference
0.07 – 0.11m/s	Griffith (1972)
<0.15 m/s	(MBTMP, 2006)

A rating curve (functional relationship between stage and discharge) was developed in order to create a discharge hydrograph for site 3 of Kama Creek in 2011. In 2012 the same rating curve was used but discharge collected was added to make a new curve for that year. The same occurred in 2013 where 2011 rating curve was used but updated with 2012 and 2013 discharge data collected. A rating curve plots measured values of stage (m) and discharge (Q m^3 sec^{-1}) obtained from the level loggers and using velocity-area method in the stream. A polynomial regression was used for each curve to show the relationship between discharge and level/stage.

R^2 values calculated for site 3 equaled 0.85 for 2011, 0.71 for 2012 and 0.80 for 2013. Using these rating curves, annual discharge hydrographs were plotted (see Figures 4.20, 4.22 and 4.24). The maximum discharge recorded in 2011, at reference site 3, was 0.092 m^3/s, taken in October. In 2012 the max discharge was 0.25 m^3/s and 2.68 m^3/s in 2013 both occurring in May. Table 4.20 below shows averages and ranges of discharge in 2011, 2012 and 2013. 2013 had highest spring/summer/fall averages and range of discharge value.

Table 4.20 Averages, and ranges for discharge values in Kama Creek in years 2011 to 2013

	2011		2012		2013	
Discharge (m^3/s)	Average	Min-max range	Average	Min-max range	Average	Min-max range
Spring	0.0227	0.0008 – 0.0427	0.0488	0.0025-0.2536	0.2313	0.0118-2.6845
Summer	0.005962	0.0001 – 0.0475	0.0123	0.0001-0.0984	0.0448	0.0118-0.5880
Fall	0.033812	0.0057 – 0.0920	0.0135	0.0099-0.0158	0.2883	0.0128-0.2477

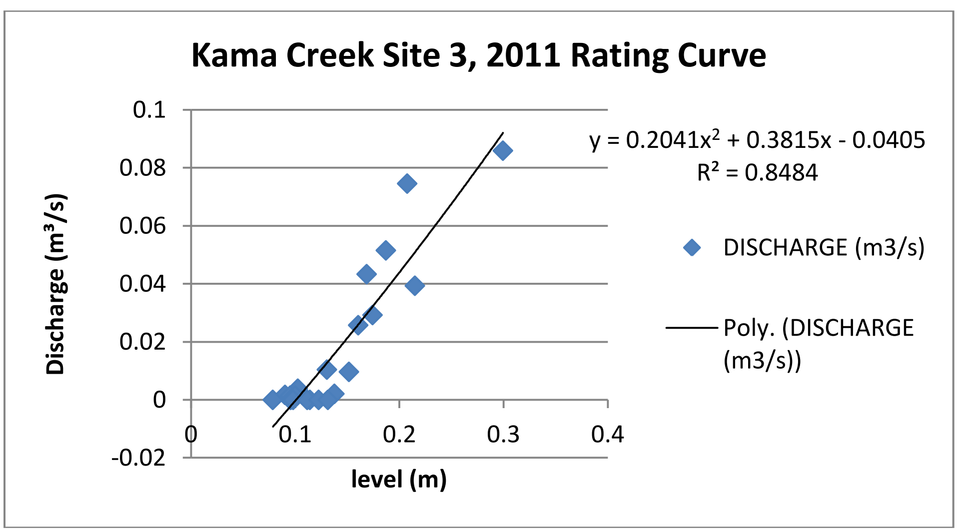


Figure 4.19 Rating Curve made using Level data and Discharge collected for 2011.

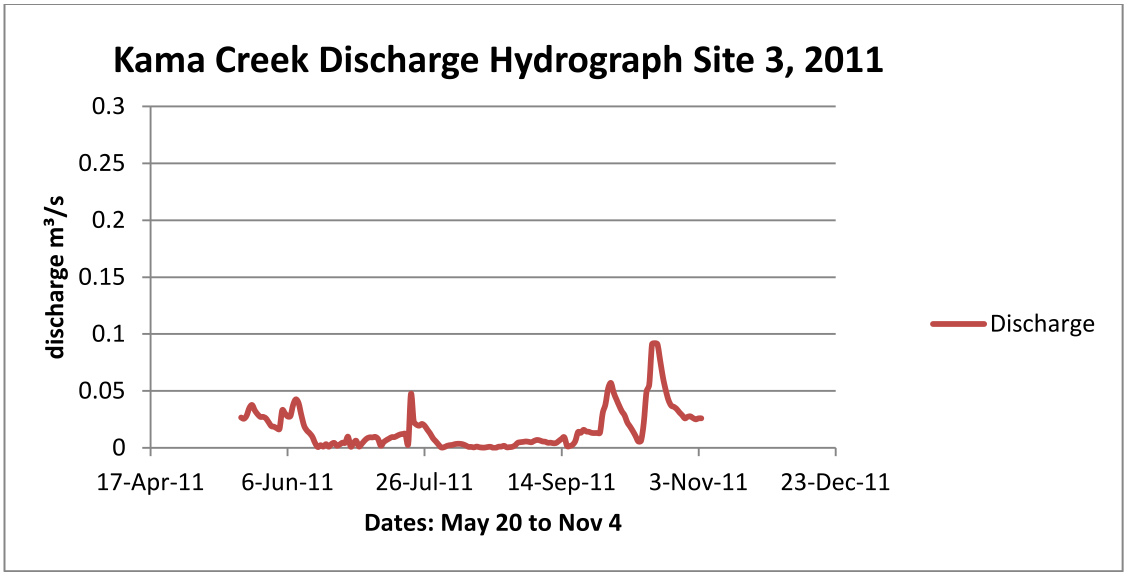


Figure 4.20. Spring/summer/fall discharge hydrograph made using rating curve for 2011, data collected from reference logger or 'site' 3.

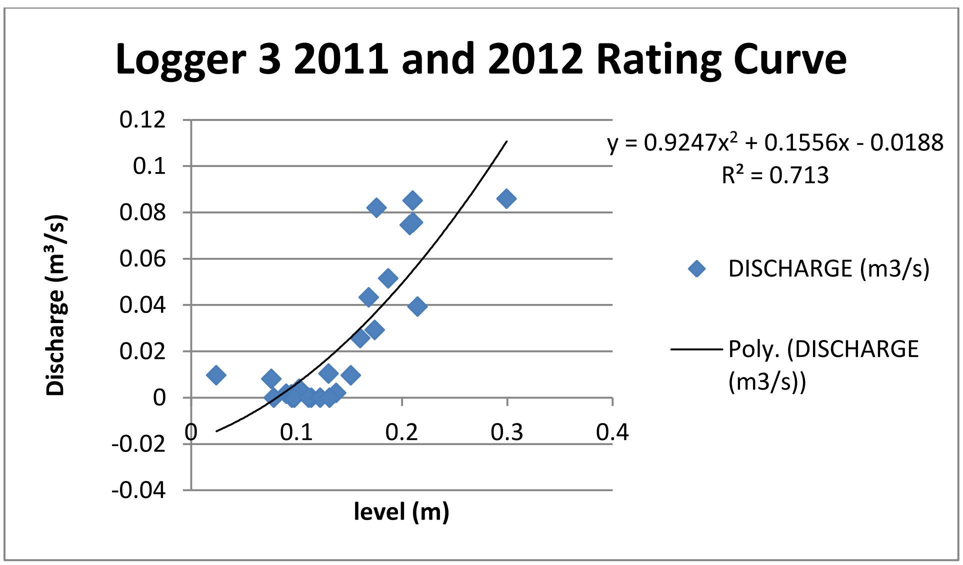


Figure 4.21. Rating Curve made using Level data and Discharge collected for 2011 and 2012.

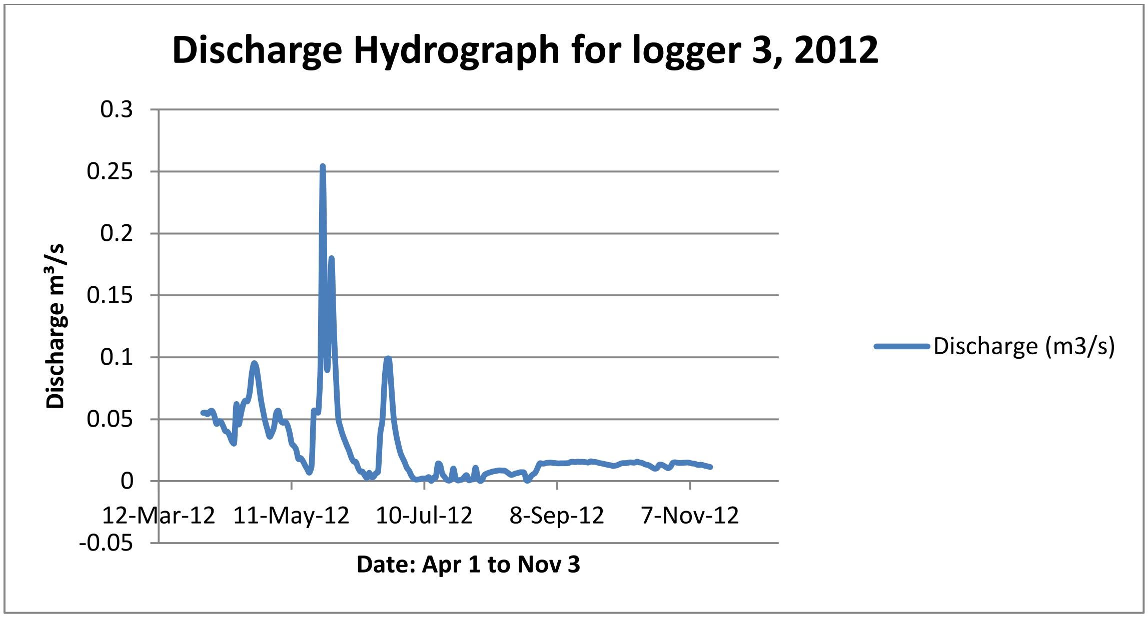


Figure 4.22. Spring/summer/fall discharge hydrograph made using rating curve for 2012, data collected from reference logger or 'site' 3.

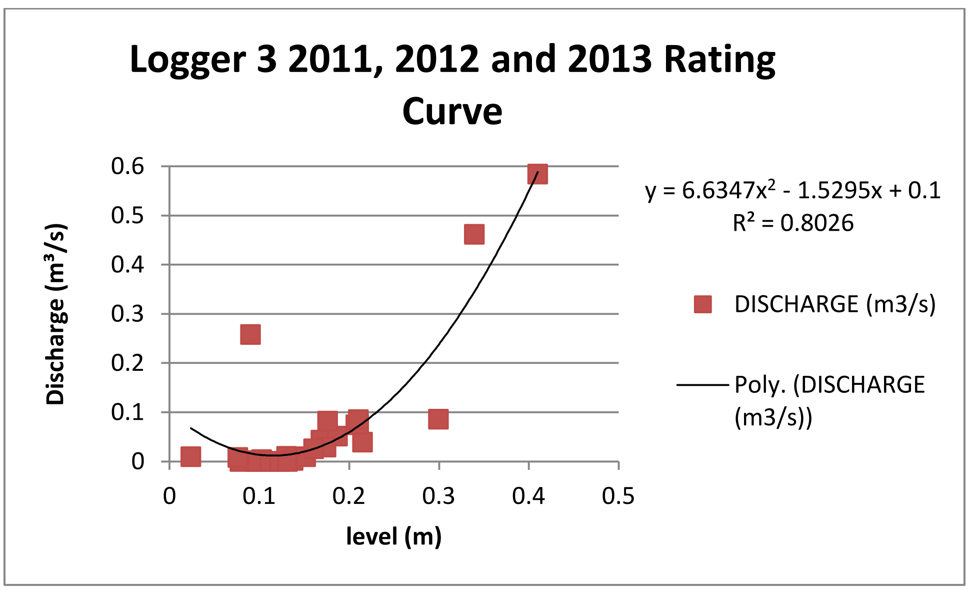


Figure 4.23. Rating Curve made using Level data and Discharge collected for 2012.

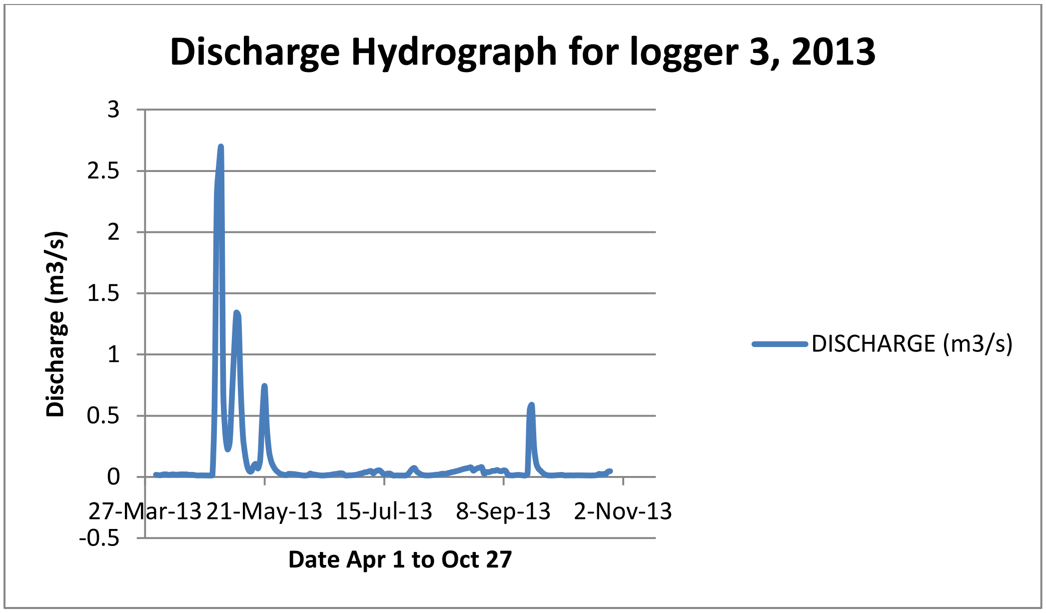


Figure 4.24. Spring/summer/fall discharge hydrograph made using rating curve for 2013, data collected from reference logger or 'site' 3.

4.6 Precipitation

Total daily precipitation data was collected using a weather station onsite and is graphed below for 2011 and 2012 (Figure 4.25). No data was taken in 2013 or 2014 as the weather station was not available. Table 4.21 below shows the averages and ranges of precipitation for 2011 and 2012. The maximum total daily rainfall for 2011 was 52.1mm and occurred on May 11. In 2012 the maximum daily precipitation was 41.2mm on July 16. Precipitation can be used to later show the relation of annual discharge to rainfall in a storm hydrograph.

Table 4.21 Spring/summer/fall Total Daily Precipitation for Kama Creek

Precitpitation (mm)	2011	2012
Average	0.66	1.35
Min–max Range	0-52.1	0-41.2

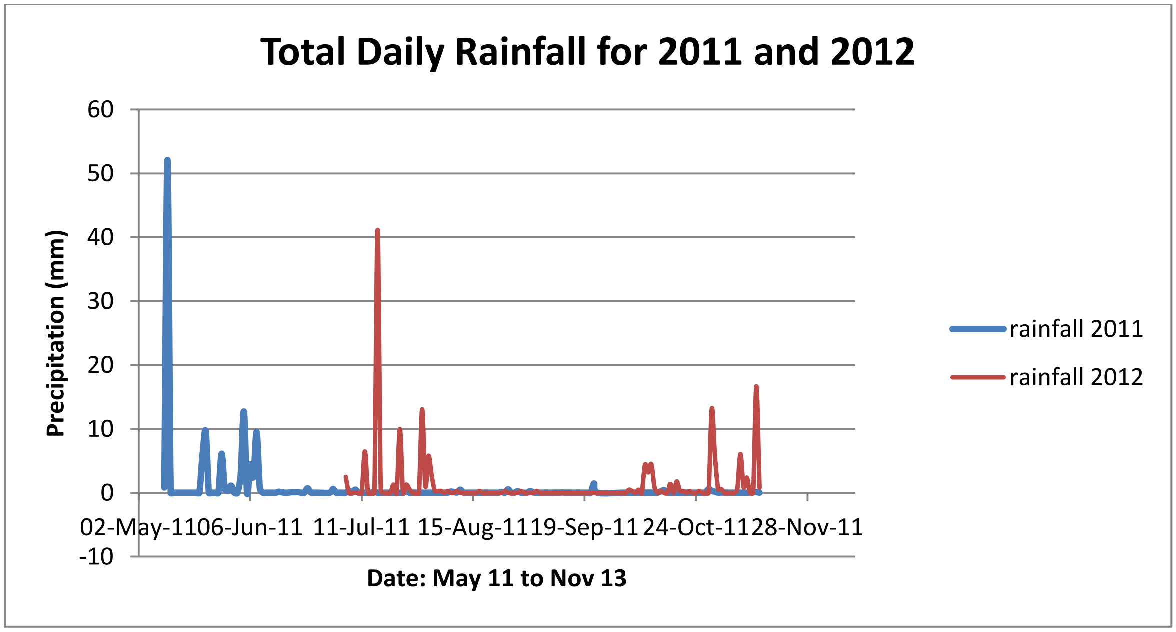


Figure 4.25. Total Daily Rainfall for 2011 taken at weather station onsite at Kama Creek
Note: 2012 precipitation was not collected until July 6.

CHAPTER 5

DISCUSSION

5.1 Evaluating Stream Restoration: Success Criteria and Protocols Used

For many, a stream restoration project is evaluated as either a success or failure based on whether it complies with requirements and guidelines. Currently, the measures of success focus on the implementation of a mitigation plan that may not conduct any evaluation for the ecological integrity of the streams being restored. Furthermore, since the plans may differ from project to project, it is hard to establish a set of criteria that can be consistently applied to measure the success of various stream restoration projects. Barbour et al, (1999) propose the use of the Rapid Bioassessment Protocols to measure the success of stream restoration. A visual habitat assessment of instream and riparian habitat quality was adapted from those protocols in this thesis to measure the success of the Kama Creek, Nipigon Bay, Ontario. Through this approach, key features were rated /scored to provide a useful assessment of habitat quality.

Further to the habitat assessment protocol, Selvakumar et al., 2010 and Miller et al., 2009 indicate that post restoration monitoring should also integrate various climate and fluvial dynamics in order to enhance visual assessments and consider the larger watershed components in addition to specific species habitat. The visual assessment performed water quantity and quality assessment, fish surveys to provide evidence of success, and an additional investigation examining hydrological modification of the stream that considered a discharge, level and flow evaluation. Together these data provide an integrated picture of several of the factors influencing the biological condition of a stream system (Barbour et al. 1999).

5.2 Habitat Assessment Protocol

Table 4.15 shows that the overall scores for each year of the habitat assessment are within the range of suboptimal conditions for Kama Creek. The old channel was at the lower end of the sub-optimal category when assessed in 2011, whereas the newly restored channel scored in the mid-range of sub-optimal in 2012 and further improved towards the high-mid range by 2014. This score alone implies that, overall, habitat improvements have occurred as a result of the restoration project; the newly restored channel is a suitable habitat to support aquatic life. (Bernhardt and Palmer, 2007). The habitat assessment also revealed that the old channel was a suitable habitat to support aquatic life. However, the overall quality/quantity of the conditions will not improve over time to increase its current score from the low end of the sub-optimal category. This is because the sub-optimal score from the old channel was based on particularly high scoring categories (i.e. epifaunal substrate; pool substrate; bank vegetation protection) that resulted from long-term naturalization since its alteration in the 1960s, and low scores in the habitat conditions dependent on channel morphology and fluvial processes. The habitat assessment therefore supports that the newly restored creek has been a success in the short term. Furthermore, section 5.4 proves that the restoration was successful in removing the barrier to fish passage at the rail culvert, which now allows access to a larger watershed habitat.

In 2011, the old channel showed an optimal amount of available cover with many fallen logs and large woody debris with favourable epifaunal colonization and fish cover. This is considered an ideal habitat feature in its present condition and the newly restored creek can be compared to this baseline as naturalization occurs. However, since the old channel is no longer able to meander within a substantial floodplain, the ability for morphology-related conditions to improve habitat (i.e. riparian vegetation zone width) are restricted (Barbour and Stribling 1991;

Pearsons et al. 1992; Wallace et al. 1996). In 2012, the newly restored channel scored poor/marginal in such conditions as epifaunal substrate, pool substrate, bank vegetation, bank stabilization and sediment deposition. The first three conditions were expected to rank lower as a result of construction and improve over time. This can be seen in Table 4.15 as epifaunal substrate improved from marginal to sub-optimal and bank vegetation improved from sub-optimal to optimal by 2014. This provides a measure of success in that the post construction establishment of the creek is occurring.

However, bank stabilization and sediment deposition were expected to decrease following construction by 2014, yet these conditions continued to drop in condition category since 2012. Sediment deposition and bank stability, therefore, represent a potential threat to the success of the restored creek as recent evidence of accelerated bank erosion and sedimentation have been observed continually through to 2014 (Cox, 2015). These conditions have dropped one whole condition category since 2012 and could cause in-stream impacts that further degrade the condition scores in all other categories (i.e. the overall assessment score). Bank stability and sediment deposition are critical conditions for ongoing monitoring, particularly to assess if further human intervention is needed. These conditions are therefore critical to the long-term success of the creek habitat as the presence of an altered habitat structure is considered one of the major stressors of aquatic systems (Karr et al. 1986). In this study accelerated bank erosion in the first few years of establishment is considered detrimental for successful habitat conditions for fish. However, some bank erosion is important to the functioning of river ecosystems and is a geomorphic process that promotes riparian vegetation succession and creates dynamic habitats crucial for aquatic and riparian plants and animals (Florsheim et al. 2008). For example, during floods bank erosion delivers large woody debris to channels (Piegay et al. 1999, Sudduth and Meyer 2006).

The following sections describe the success of these various conditions in the context of future monitoring needs.

5.2.1 Successful Habitat Conditions

It is evident that the restoration design features of the new creek successfully allowed for the newly restored channel to score high in categories such as pool variability, channel flow status, channel alteration, frequency of riffles, channel sinuosity and the riparian vegetation zone width. These conditions were poor or marginal at best in the old channel as a result of the alterations in the 1960s, which was the impetus for the restoration design.

Because the old channel was constructed as a drainage tributary, it had few shallow/small pools and one large pool compared to the restoration channel that optimized pool variability with an even mix of large deep pools and small-deep, small-shallow pools (U.S. EPA, 1983). By 2014 the combination of pools and riffles or bends in the newly restored channel continued to provide a visible source of high-quality habitat (Cushman 1985) and a noticeable frequency of fauna in the newly restored channel increased the diversity of the stream community (Hughes and Omernik 1983). Overtime the stream morphology should continue to diversify pool sizes and the extent and quality of the riffles though, higher flow over the riffles will erode and enlarge them while slower velocities in the pools will cause more deposition and swallowing (Philip Fralick, pers. comm, April 2015). Long-term measurements of riffles is critical to ensure that the restored creek sustains a similar ratio of those constructed (Statzner et al. 1988), and that pool dimensions (i.e., length, width, oblique) are greater than half the cross-section of the stream for separating large from small and 1 m depth separating shallow from deep (Beschta and Platts, 1986).

Channel flow in the old channel could only fill approximately 50% of the available channel leaving riffles, cobbles and much of the steambed exposed. The amount of suitable substrate for aquatic organisms was therefore limited (Hupp and Simon 1986, MacDonald et al. 1991). However, the newly restored channel was designed to provide a low-gradient stream.

This design feature limited the flow in the summer months to expose logs and snags (and thereby reducing the areas of good habitat) but the fall period provided optimal flow conditions for coaster brook trout to use the creek. The fall of 2012 and 2014 assessments show an optimal channel flow status as water reaches the base of both lower banks, and a minimal amount of the channel substrate left exposed. However, monitoring should ensure that these conditions are consistent and do not degrade over time if erosion and sedimentation occurs, and/or if extremely dry summer conditions extend into fall (Ball 1982, Hicks et al. 1991). Extreme dry summers may pose a threat to fish if they are trapped in drying pools. Future monitoring and further mitigation may be needed if the pools continue to fill with sediment.

Channel alteration was prominent in the older channel as a result of incremental interventions of artificial embankments, riprap, and other forms of artificial bank stabilization that minimized scouring (Simon and Hupp 1987; Rankin, 1991). The new channel was restored to mimic the natural bends and meanders of the historic natural river bed that existed prior to the 1960's, and as a result of this design, was intended to be optimal in the channel alteration category. The problem is that the new channel mimicked a two dimensional plane view of the channel but not the other dimension – depth, which is just as important. The depths of the curved and straight portions of the channel were changed to make various sized pools etc, which were not present at those depths in the original channel. This is not mimicking the natural system as natural systems are three dimensional not two dimensional. Potentially getting the third dimension wrong will mean that the stream will make necessary alterations to its course and depth to try and establish a better flow equilibrium. This is why we see, and will continue to see, extensive erosion and deposition. Because some channelization was present by 2013, the overall ranking of the newly restored channel fell to suboptimal. Monitoring channelization is important to ensure that this natural channelization stabilizes within the newly restored channel, and that pools and riffles maintain their habitat features despite natural channeling.

Channel sinuosity in the newly restored creek was a particularly successful condition as the length of the creek was increased 3-4 times longer as a result of bends, compared to the old channel which was relatively linear (Bain and Boltz 1989). The newly restored channel was better able to handle surges when the stream fluctuated as a result of storms (Gislason 1985) and the bends adequately absorbed energy to protect the stream from excessive erosion and flooding (Gordon et al. 1992). Observations from 2012 to 2014 continue to show a stable channel that does not exhibit progressive changes in slope, shape, or dimensions, although short-term variations have occurred within the seasonal stream channel (Statzner et al. 1988). Future monitoring of storm events (i.e. storm hydrographs) would help to determine how extreme events may affect this rating, and particular attention should be on pool/riffle specifications in the spring and fall to compare the affects of natural channelization on habitat features.

The improvements to the riparian vegetation zone were primarily successful because the newly restored channel was constructed within the historic floodplain that existed for Kama Creek before the 1960s diversion. Since the old channel dug in the 1960s was located within 6 meters of a number of cottages the vegetative zone did not provide an ideal buffer to pollutants that may have enterered the stream from runoff and erosion (Barton et al. 1985, Naiman et al. 1993, Hupp 1992). As long as the vegetation zone of the newly restored channel is undisturbed, it should provide an optimal area to support a robust stream system and vegetation zone that is remote from roads, cottages and the rail line (Platts et al. 1983, Rankin 1991, Barbour and Stribling 1991, Bauer and Burton 1993).

5.2.2 Improving Habitat Conditions (naturalization)

Although the newly restored channel rated poor in the epifaunal substrate category and the pool substrate category, this was due to low scores from the lack of cover and natural sedimentation occurring in the creek directly after construction. Despite the design features maintaining their structure and function in the years immediately following construction, by 2014, the majority of pools were filling up with sediment and not sustaining their structure. If this sedimentation does not decrease, there will be little to no pools available in the creek from the original design. However, the newly restored channel has established a variety of natural epifaunal structures in the stream that increased the 2014 rating to sub-optimal habitat despite these obvious changes to the pool structure. Furthermore, firmer sediment types (e.g. gravel and sand) and some rooted aquatic plants were observed to support a wider variety of organisms (U.S. EPA, 1983) and substrate types within the pool substrate category (Beschta and Platts, 1986).

Provided the boulders and riffles maintain their positioning in future monitoring, the remainder of the scoring in these two categories are expected to increase to optimum as cover and natural fluvial processes further establish the epifaunal and pool substrate. This indicates that epifaunal and pool substrate should not be limiting factors to the restored habitat in Kama Creek (Wesche et al. 1985; Gorman 1988; Rankin 1991; Barbour and Stribling 1991; Pearsons et al. 1992; Wallace et al. 1996).

5.2.3 Habitat Conditions of Concern

The newly restored channel responded well to the 2012 post-construction environment and showed few escalating signs of erosion such as crumbling, unvegetated banks, exposed tree roots, and exposed soil (Ball 1982, MacDonald et al. 1991, Armour et al. 1991). Rather than progressively stabilizing, however, the newly restored channel showed an increase in eroded banks that indicated a potential problem with sediment movement and deposition, and suggested a scarcity of cover and organic inputs to streams (Osborne et al. 1991, Rosgen 1994, 1996). However, the vegetated zone and banks of the newly restored creek were well vegetated and diversifying by 2014. The increase in erosion, bank slumping and sediment deposition appears to be a result of spring surges and high flows of water in 2014 that caused more erosion of banks and sediment deposition in the new channel. The areas from the design that included a number of bioengineering methods to reduce bank erosion rates (i.e. live staking and brush matting) did, however, show more resistance to these potential storm surges. Some bank erosion is important to the functioning of the stream system and monitoring should consider the difference between excessive and accelerated erosion impacting the design features and the desirable amount of erosion that occurs in natural channels. Differentiating between extensive bank erosion caused by human activities and land uses versus those caused by natural geomorphic processes and stream evolution warrants attention in current science and management efforts (Florsheim et al. 2008).

5.3 Water Quality Assessment

The overall results of this study show that both the old channel and the newly restored channel exhibit similar water quality measurements that reflect natural conditions, are within the Canadian Environmental Quality Guidelines CEQG standards for aquatic life, and are within the ideal conditions for the sentinel species, brook trout. This result was expected as there were no sources of contamination near the stream catchment and data was collected to ensure that construction activities that immediately impacted dissolved oxygen, temperature and turbidity were not persistent in the newly restored channel. As they relate to ideal coaster brook trout habitat, improvements to water quality were evident with certain parameters such as conductivity, temperature and pH. Minor exceptions include parameters that were particularly impacted by construction, such as total dissolved solids (TDS) and dissolved oxygen and water quality should continue to monitored to ensure these parameters stabilize.

5.3.1 Total Dissolved Solids

Brook trout do not have specific requirements for the level of total dissolved solids (TDS) in the water column but Kerr (2000) recommends >20ppm and <50ppm. Fish have been observed in water with TDS measures lower than 10 ppm; however, these fish are often underdeveloped and do not reproduce well (Raleigh 1982). The sampled levels of TDS within Kama Creek for all sites had a range of 15 ppm to 360 ppm. The low values (<20ppm) were found in 2011 only. Average total dissolved solids (TDS) were high in the Kama Creek in both the modified channel and natural channel, 103.7ppm for 2011 and 279.9 ppm for 2012. TDS values in lakes and streams are typically found to be in the range of 50 to 250ppm. In areas of especially hard water or high salinity, TDS values may be as high as 500ppm. It is normal for streams to dissolve and accumulate fairly high concentrations of ions from the minerals in the rocks and soils. If these deposits contain salts (sodium chloride or potassium chloride) or limestone (calcium carbonate), then significant concentrations of Na +, K +, Cl- will result. If TDS levels are high, especially due to dissolved salts, many forms of aquatic life can be affected. So TDS would be an important parameter to monitor closely in the future (Johnson et al. 2015). However, according to literature there are no significant effects from exposures of high TDS on trout up to 2000mg/L (Chapman et al., 2000) or for exposures after fertilization (Stekoll et al., 2000). Affects to growth (i.e. smaller size) in trout has been attributed to low TDS values less than 20 ppm (Lennon 1967). TDS within Kama Creek is therefore not considered to be a limiting factor for further habitat enhancement post restoration but should be monitored.

5.3.2 Conductivity

Brook trout occur in waters with a wide range of specific conductance, although high specific conductance usually increases brook trout production (Cooper and Scherer 1967). Similar to TDS, brook trout do not have a specific range of conductivity which limits their habitat. Freshwater can vary between 50 to 1500 hs/cm (Boyd, 1979). As fish differ in their ability to maintain osmotic pressure, the optimum conductivity for fish production differs from one species to another. Stone and Thomforde (2004) recommended the desirable range 100-2,000 µS/cm and acceptable range 30-5,000 µS/cm for fish culture in ponds but this is not specific to brook trout. A high specific conductance is considered beneficial to the growth of brook trout (Raleigh 1982) and (Rintamaki 1986). Conductivity data collected in Kama Creek ranged from 30 µS to 767 µS and averages did increase from 2011 to 2012 when comparing the modified channel and natural restored channel. The few low values (<100) found, like TDS, were only recorded in 2011. 2011 conductivity ranged from 30 µS to 767 µS. The range of values for 2012 was 403 μS to 672 μS, and should not be a concern for the newly restored channel.

5.3.3 pH

Brook trout exhibit a larger tolerance to pH variability than many other salmonid species (Halfyard et al. 2008). Testing of brook trout conducted in a lab setting has yielded a range of tolerable pH values from 3.8 to 9.8. The optimal pH range for brook trout is 6.5-8.0, with a tolerance range of 4.0-9.5 (Raleigh, R. F. 1982). These levels of acidity provide the most productive habitat (Rintamaki 1986). The pH of Kama Creek during the sampling period ranged from 7.0 to 8.6. Averages were 7.8 for both site 1 and site 3 in 2011, 7.4 for site 3 in 2012 and 7.6 for site 2 (the newly restored channel) in 2012. These values fall within the most productive range for brook trout. The data suggest that pH is not a limiting factor in brook trout habitation of Kama Creek; acidity is within the ideal range.

5.3.4 Dissolved Oxygen

The ability of water to hold oxygen in solution is inversely proportional to the temperature of the water. For example, the cooler the water temperature, the more dissolved oxygen it can hold. This component in water is critical to the survival of various aquatic life in streams, including fish (McKee and Wolf 1963). Dissolved oxygen requirements can vary greatly for brook trout populations, but there are established optimum levels and absolute minimums. Dissolved oxygen should not drop below 5 mg/L to be tolerable for brook trout (Raleigh 1982; CWQG 2003). Low levels of dissolved oxygen can affect growth and swimming speed and potentially cause mortality if levels drop too low. Site 1 in 2011 had an average of 9.3mg/L and a temperature of 10.9°C. In 2012, site 2 had a mean dissolved oxygen reading of 10.9mg/L with a mean temperature of 9.5°C. This trend occurs at all sites; as temperature decreases the amount of dissolved oxygen increases. For 2012 dissolved oxygen (10.3 mg/L), however, only slightly exceeded optimal range for aquatic life but still falls within the guideline of >5mg/L. The values for DO in Kama Creek ranged from 3.3mg/l to 14mg/L. The low values <5mg/L were only found in 2011 in the old channel and a healthy range of 8.1mg/L to 14 mg/L were measured in the newly restored channel. The newly restored channel was built with an adequate amount of riffles to keep DO oxygen levels up but this will depend on temperatures of the water and air.

The successful water quality results are further supported by a recent benthic macroinvertebrate survey to identify pollutant indicators for Kama Creek (Dr. Ken Deacon, 2015). Communities from two sites in Kama Creek (one above and one below the railroad culvert) were surveyed during 2009 to provide baseline data about the pre-treatment condition of the stream and again in September of 2014 to determine the status of post-treatment recovery. The overall findings of the aquatic benthic macroinvertebrate communities indicate high quality fish habitat and good water quality.

5.3.6 Water Temperature

Typical brook trout habitat conditions are those associated with a cold temperate climate, and cool spring-fed ground water (MacCrimmon and Campbell1969). The optimal water temperature range for brook trout to feed and survive falls between 11-16°C, according to Baldwin (1951), Mullen (1958) and (MacCrimmon and Campbell 1969). Water temperature for Kama Creek is within ideal ranges for brook trout, with minor exceptions.

Warm water temperatures appear to be the single most important factor limiting brook trout distribution and production (Creaser 1930; Mullen 1958; McCormick et al. 1972).

Brook trout will not live or thrive in temperatures warmer than 20°C, Bean (1909), McAfee (1966) and Brasch et al. (1958). 2013 temperatures had the highest maximum summer temperature of 23.6°C and this could pose danger to fish though it was only one. The deep pools observed in the newly restored channel will hopefully provide critical habitat for brook trout rearing and summer refugia in the stream (Kerr, 2000) as long as they don't fill in from sedimentation.

5.4 Fish Surveys

Fisheries data was collected by electrofishing a portion of reach 1 and 3 (above the culvert) on June 2 of 2011 before the restoration activities occurred and then again in reach 2 (restored channel) on July 23 of 2014. In 2011 14 brook trout and 45 rainbow trout were found downstream the culvert prior to restoration. No fish were found above the culvert as a result of the impasse created by the perched culvert. In 2014, 14 rainbow trout were captured but no brook trout were identified in the electro fishing sample. There is a possibility that the low numbers of trout captured in the new channel was because they migrated to above the culvert which was not monitored but many fish were observed above the culvert post restoration. This is a good sign that they will keep using the stream in its entirety and have plenty of refugia and spawning grounds but electrofishing should be repeated to confirm fish are present.

During electrofishing surveys a range of other fish species (salmon, white suckers, lake chub, stickleback) were collected above and below the remediated culvert in 2011 and 2014 (See Table 4.17). Coho salmon numbers collected were of interest, with 62 caught in 2011 and 68 in 2014 in the newly restored channel. Though they were not the species of interest and therefore no habitat requirements were studied on them. More electrofishing studies should be completed to confirm the presence of brook trout in particular, and should expand in scale to include metrics such as number of intolerant species, number of native species, percent of catchable salmonids, etc. These metrics can be used as a dependent variable for statistical comparisons between reference and impacted sites.

Fish passage through structures such as culverts and other artificial barriers in streams is critical to maintaining connectivity among habitats. Restoring fish passage is an effective way to increase the availability of habitat and can result in relatively large increases in potential fish production (Roni et al, 2000). New habitat has been constructed and fish are now able to use the section of Kama Creek above the railroad culvert for the first time in 50 years. Kama Creek will probably support an excellent fishery, especially if stream flow remains uninterrupted in the fall.

5.5 Stream Flow, Discharge/Level and Precipitation

Although the Kama Creek was found to have intermittent seasonal flows, it serves as a corridor for the fish species found above and below the culvert and allows them to move throughout the stream when flow is present, providing longitudinal connectivity. Elson (1939) reported that brook trout prefer moderate flows. Griffith (1972) reported the focal point velocities for adult brook trout range from 0.7-0.11m/s, with a maximum of 0.25m/s. Spring flows in 2011 and 2013 were slightly high according to these requirements of brook trout and this could pose a threat to fish but the overall range is within adult brook trout requirements. The very low flows (<0.05m/s) that occurred during dry summers may also pose a threat to fish but since the newly restored channel was designed with deep pools specifically for young brook trout refugia, Kama Creek will probably support an excellent fishery as long as the pools do not fill in excessively and this should be the focus of future monitoring.

Rating curves (functional relationship between stage and discharge) were developed in order to create a seasonal discharge hydrograph for site 3 of Kama Creek in 2011, 2012 and 2013. A polynomial regression was used for each curve to show the relationship between discharge and level/stage. R^2 values calculated for site 3 equaled 0.85 for 2011, 0.92 for 2012 and 1 for 2013. Very little flow data was taken in 2013 and assumptions made for the rating curve that year may not be as accurate as the multiple discharge measurements that were used for the 2012 and 2014 calculations. The rating curves were positively correlated (See Figures 4.19, 4.21 and 4.23) showing that as discharge increases so does depth. Increased depth in pools will therefore cause higher flow and allow more fish to move through into this habitat.

The greatest factor controlling stream flow, by far, is the amount of precipitation that falls in the watershed as rain or snow. However, not all precipitation that falls in a watershed flows out immediately, and a stream will often continue to flow where there is no direct runoff from recent precipitation (USGU, n.d.). Kama Creek is known to be a flashy stream and large rainfall events will cause high discharge and flow. Some of this water will infiltrate the soil and eventually enter the stream by seepage into the stream bank. Some of the water may infiltrate much deeper, recharging ground-water aquifers (Konrad, C.P., and Booth, D.B., 2002). The amount of water that will soak in over time depends on the substrate of the stream which consists mostly of highly permeable sand and gravel underlain by impermeable lacustrine clay (See Figure 4.2b and c). Before the restoration occurred and the layer of clay was not known to exist there was concern that this surface material would simply promote water seepage back to the 1960s diverted channel (reach 1) because it was dug to a lower elevation. However, the restoration activities revealed that the restored channel was either within the original (natural) Kama Creek floodplain and was dug overtop a clay bottom that had developed from the meandering of the original (pre-1960s) creek, or, more likely, the clay layer represents deposition during a high-stand of Lake Superior. This means the newly restored channel is at least in part underlain by an impermeable substrate that will not allow groundwater recharge but will also not allow water supplied by surface runoff to infiltrate through the stream bottom to a lowered water table. The groundwater seep (See Figure 4.2) found on the bank of the new channel is most likely standing water from a perched aquifer and the thick clay layer is preventing it from infiltrating.

Other factors such as land cover will also have a great impact on infiltration and rainfall runoff. But Kama Creek has optimal bank vegetation protection (See Table 4.15) and should slow runoff by allowing water to seep into the ground. There the infiltrating water will encounter the impermeable layer not far below the surface and some of this will be delivered to the new channel through seepage along its banks (Figure 4.2a). Future monitoring should include more rigorous fluvial geomorphology protocols such as calculated bankfull discharge and storm hydrographs to ensure flooding is properly monitored.

5.6 Limitations/Lessons Learned

This study was successful in obtaining data that could be used to evaluate some aspects of long-term performance of the Kama creek restored stream. However, a number of areas were identified where additional information could have significantly improved the quality of the evaluation.

The visual habitat assessment used was a good way to evaluate conditions in the stream in relation to fish habitat quality and quantity. It also provided a method for standardizing data collected for accurate comparison from year to year. However, this may not be the best way to measure all aspects of a stream restoration project as it is bias towards requirements for aquatic life only and lacks a focus on hydrologic effects of the stream. One example of this is the channel flow status condition category. Poor conditions for fish are very little water in the channel with most water standing in pools and optimal conditions are where water reaches the base of both lower banks, and a minimal amount of channel substrate is exposed. This would be opposite if you were rating channel flow status in terms of erosion concerns. The more water filling to the banks would actually cause more erosion and possibly flood conditions. High flows in spring would also not be ideal for survival of fish.

Stream restoration is a holistic process that requires consideration of all physical and biological components of the stream system and its watershed (MCDEP, 2010). It also requires sharing information between scientists and field managers; and adapting the objectives, treatment/design, monitoring plan, and/or policies to new information in the hopes of achieving better results (Johnson et al., 2002). Because this project focused on the biological benefits it neglected some important physical components that if paid more attention to could have avoided some concerns. One example of this is that boulders were placed in riffles and not compacted down into the substrate as this would prevent interstitial spaces for fish habitat and stir up sediment. However if boulders were pressed firmly into the sediment this would have prevented many of them from rolling into the riffles and pools (Philp Fralick, pers. comm., April 2015).

5.6.1 Additional Concerns

In addition to the habitat assessment flow, substrate size and fish populations in the stream were measured to provide a better overall evaluation. These measurements all have disadvantages and this study would benefit if additional information was collected.

Determination of bankfull level is an important variable in stream monitoring and was not measured in this study. Bankfull level can be difficult to identify. Field experience using field indicators, such as channel vegetation, flow lines, and depositional areas, such as bars, can aid in determining bankfull level and is one mode of reducing uncertainty in this technique (Rosgen 1996, 2006). However, these indicators can be misleading and experience, including knowledge of vegetation and channel processes, is critical when using field indicators for bankfull determination (Rosgen 1996, 2006, Nagle 2007, Hey 2006). This would be an important variable to measure on Kama Creek to identify bankfull discharge and flow.

Lack of experience and evaluation on channel processes through field data (flow and sediment) monitoring can limit accuracy of results. Simple rating curves were created in this study using discharge from flow measurements taken and level that was recorded. These simple rating curves show the positive relationship between discharge and level in the stream and were used to calculate daily seasonal discharge but only used to show a general trend and ranges. Not enough flow data was taken for these curves to be statistically sound. This is especially seen in 2013 where the rating curve produced is only based on three flow measurements taken (See Figure 4.23). In this thesis the relationship between discharge and level was justified because flow was collected from a level logger at site 3 (see Figure 3.4) in the culvert that acted as a weir so discharge was treated as flow over a weir (Herschy, 1995). However, in natural channels the water-surface slope varies for unsteady flow, the cross section changes with sediment deposition and erosion, and the resistance coefficient changes with bed and flow conditions. The relationship between stage and discharge can be modified by a great number of factors that result in changes in shape and position of the rating curve, included changes to the channel cross-section due mainly to scour and fill, growth and decay of aquatic vegetation and log and debris jams (Herschy,1995 ; Kennedy,1984; Rantz et al., 1982b). So when the flow in Kama Creek departs from steady stream flow the simple rating curves produced will no longer be sufficient to predict the discharge of the stream.

Particle-size distributions obtained from pebble counts must be accurate in order to be useful for a study objective. Estimates of bedload transport rates, for example, vary significantly if the bed-material percentile particle-size used for the computation varies slightly (Gessler et al. 1993; Bunte 1994). The pebble counts were conducted using a step-toe process where the stone fell at your foot was picked up and measured. Double counting most likely occurred due to small sampling-point spacing over samples cobbles and boulders. The bias against fines has the most pronounced effect on the cumulative particle-size distribution if the bed contains a large number of difficult-to-sample fines and thus presents a large opportunity for neglecting fines. Similarly, the tendency of avoiding cobbles and boulders has the most pronounced effect on the cumulative particle- size distribution in beds containing a large number of difficult-to-sample cobbles and boulders. Taking photos and using online software to measure particle size may pose less error and should be used in future monitoring on Kama Creek.

Electrofishing a stream has its advantages but it does also have some disadvantages. Sampling efficiency is affected by turbidity and conductivity, which may have been high on the sampling day in 2014, but was not recorded. Although less selective than seining, electrofishing is size and species selective and effects of electrofishing increase with body size (Reynolds

1983). Small young brook trout may have been hiding in the deep pool of the new channel. These deep pools were not available in the old channel. Young brook trout in the new channel may have not been recorded using electrofishing but this does not mean they are not present. Future monitoring should include seine or drift netting in addition to electrofishing.

CHAPTER 6

CONCLUSION

6.1 Summary

The research validates that the Kama Creek Restoration Project has improved the environmental health and stability of a small-scale stream, and improved coaster brook habitat in the Nipigon Bay area in comparison to it pre-restoration state. The baseline data collected pre and post restoration were used within a habitat assessment protocol and ranked the Kama Creek as a suboptimal condition for brook trout immediately after restoration. The immediate re-establishment of the creek was well underway by 2014 and it is highly likely that conditions related to naturalization (i.e. vegetation cover and epifaunal substrate) will improve by 2016 to increase the ranking of the new creek to optimal. This may not be true if infilling of the pools and extensive erosion of the riffles continues, but this must be monitored and necessary mitigation would need to take place. Some bank erosion is necessary for the functioning of the stream system so monitoring bank erosion should differentiate between extensive bank erosion caused by human activities and land uses versus those caused by natural geomorphic processes and stream evolution.

The creek is healthy in terms of water quality and temperatures in the newly restored channel. Water quality is ideal for fish and other aquatic life according the Canadian Environmental Quality Guidelines for Aquatic Habitat. Although there is statistical variability between the old and newly restored channel of Kama Creek, in terms of water quality, the new channel showed improvements with increased TDS and conductivity. Temperatures observed were adequate for brook trout. The observed temperatures in the late summer, demonstrate the importance of Kama Creek as a thermal refuge.

The results of the habitat assessment protocol further supports the successful re-establishment of the restored creek habitat as riparian vegetation zones, although young, have established without intervention and the visual presence of riparian zone insects and herbtiles have increased incrementally since the restoration activities. Fish surveys show that there is a diversity of fry and younglings present in both the old channel and newly restored channel (many include trout), and that fish are present in equal numbers in the pools above the railway tracks where they were absent before restoration activities occurred. The barrier to fish passage has successfully been eliminated and the fish now have access to many riffle pool sequences in an area double the size of the old creek. Discharge and precipitation measurements for the years collected on average prove suitable to maintain ideal habitat levels in pools and through the culvert passage, primarily in the fall when nursery and spawning conditions are most critical. Average flow was high in 2011 but within optimal range in 2012. Data shows very low <0.05m/s minimum flows in the summer of 2011, 2012 and 2013 and this could be caused by no rain or drought conditions. Kama Creek is a flashy stream with high flows in the spring and fall and low flows, sometimes no flow, in the summer. This is not an issue of restoration but of climate and is why the design called for deep pools to hold water in these dry conditions. As long as pools do not fill in extensively fish should be able to take refuge but this should be closely monitored.

Table 6.1 provides a summary of the success criteria that were used for the Kama Creek Restoration project, adapted from Harris (2005). Although some of the criteria were not fully satisfied (i.e. bank erosion and sediment deposition) the Kama Creek Restoration project is deemed a success for brook trout habitat provided these conditions stabilize. This is based on the

Rapid Bioassessment Protocols for instream habitat; the improvements in water quality parameters; temperature and flow results and observations on fish presence above the culvert.

Table 6.1. Sample Success Criteria and Monitoring Parameters used for the Kama Creek Restoration Project

Restoration Parameter	Example Success Criteria	Example Monitoring Parameter(s)	Signs of Success in restored Kama Creek
Instream habitat improvement	Project improves rearing habitat within restored reach	Frequency and depth of pools, water quality and temperature	Frequency of riffle/pools increased from to >7 Pools present are deep and cold Water quality falls within CEWQ guidelines
Streambank Stabilization	Reduced bank erosion	Percent of bank that is fully vegetated, discharge and level	Bank stability ranked suboptimal and vegetation protection ranked optimal
Riparian Planting/control	Survival meets or exceeds contract specification, Reduced bank erosion	Amount of native vegetation present	Vegetation protection and Riparian Zone ranked optimal conditions
Fish Passage Improvement	Area of habitat made accessible, sign of Fish using stream habitat above culvert/railway	amount of habitat made accessible and fish surveys to show presence	Approx. 600m² of Fish habitat made available; Fish observed above culvert
Substrate Improvement	Substrate size within ideal range for brook trout	Pebble counts	50% the substrate particles are within 13–128 mm preferred (movable) spawning substrate size range for salmon and trout species in channel above culvert (Bjornn and Reiser, 1991).

Note: Table adapted from
http://forestry.berkeley.edu/comp_proj/DFG/Monitoring%20Implementation%20Effectiveness%2Fisheries.pdf
Procedures for Monitoring the Implementation and Effectiveness of Fisheries Habitat Restoration Projects

Monitoring water quality should continue to focus on dissolved oxygen, as this parameter should increase gradually to the optimal range over the first 5 years of re-establishment after restoration. This should occur as water temperature should continue to drop as shade increases from a maturing vegetation zone. TDS measurements should continue to decline following construction of the channel. Water temperature remains in a suitable range for coaster brook trout. Discharge measurements show that velocity has reduced to a more suitable level for coaster brook trout habitat, and improved cascading pools now exist within a more sinuous stream channel.

Sinuosity and velocity should continue to be monitored to ensure that the ideal state set in motion from the restoration design is not degraded from fluvial morphological changes over time. Discharge levels and durations should also be monitored to ensure that the yearly averages of this intermittent stream do not exceed the optimal range. Most critically to the success of the restoration activities, the presence of eroding stream banks should be recorded to ensure that current erosion rates subside as the creek stabilizes. The slipping of boulders and cobble substrate within each cascading pool has continued to affect the ideal dimensions of the pool into 2014, and monitoring for increased stability of the cascading pool sequence should determine if the pools will naturally stabilize or if human intervention is periodically required during no-flow periods to re-form the riffle/pool/riffle sequence. The stream would benefit from planting more native tree species to provide stronger root mats for epifaunal substrate and also to reduce erosion.

The benthic populations should be monitored for increased establishment to a more diverse community, and fish surveys should continue yearly to ensure similar numbers throughout the nursery period, and in particular, focus on the presence of coaster brook trout. They should also focus on seasonal variations and include water levels and discharge as they have an impact on fish. These studies will be repeated from spring/summer/fall each year on the entire extent of the restored stream for 5 years after implementation until 2017. Fish population numbers and percent habitat increase should be measured in line with existing Ontario Ministry of Natural Resources Inventory protocols in order for monitoring capacity to be maintained over the long-term. Monitoring should continue on specific indicators related to the concerns of the baseline monitoring procedure used in this research. In particular, monitoring in the short term should be used as a decision making tool to determine if human intervention is required to stabilize banks. Storm hydrographs can be used to understand the risk of high intensity storms and existing in-stream woody debris and minor adjustments to the channel position can be made/monitored to understand how the channel hydraulically deflects flows away from failing banks. Additionally, collecting flow and sediment data in different reaches to optimize and physically compare erosion and transport rates can lend further insight to the stream dynamics above and below the culvert. Pebble counts should be performed in the new channel to assess particle size and distribution after 2014, when more time has passed for naturalization of the channel substrate.

Because the electrofishing survey was limited in 2014, the exact number of brook trout using the creek has not been determined. Further fish surveys can be generated along with sediment and flow data to provide a correlation between existing species and sedimentation rates over time.

Post-project performance evaluation is needed to avoid repeating mistakes and to develop an understanding of how streams respond to restoration actions. Stream geomorphology and ecology are complex, and we cannot predict precisely how the river will respond to a given treatment. Our restoration efforts are best viewed as experiments, from which we can learn valuable lessons to improve future project design (Kondolf, 1995a). Future success of the project will continue to be measured by the resulting increase in biological productivity of the creek, for example, the increase of brook trout populations and benthic macroinvertebrates. And other criteria that will confirm ecological success are; quantifiable reduction in bank erosion rate, the bank remains undamaged, enhanced habitat diversity and no substantial change in stream bank erosion and/or sediment deposition (Roni, 2005).

There is clearly a need for greater rigour in ecological restoration projects (Murray and Marmorek, 2004). Successful monitoring plans are project specific and designed to provide adequate data to assess progress towards meeting stated objectives and provide technical basis to support corrective actions if goals are not met. Monitoring stream restoration projects should be a method that embraces uncertainty in the design of the projects and treats these projects as continuous, cyclic experiments, yielding results to be incorporated into future decisions. Sharing information between scientists and field managers; and adapting the objectives, treatment/design, monitoring plan, and/or policies to new information in the hopes of achieving better results is critical (Johnson et al., 2002). Functional ecological restoration should include efforts specifically targeted at restoring critical structural ecosystem features (e.g., riparian vegetation) and critical ecological processes, such as nutrient dynamics (e.g., flux or uptake of nutrients), the input of organic matter, and productivity (Beechie et al. 2010, Bernhardt & Palmer 2011).

Though the Kama Creek did show signs of success there are hydrologic factors that need to be continually monitored and altered when necessary. The stream is not sufficient to be left to nature at this time and human intervention will be required for years to come, >10 years, is the minimum monitoring time suggested by Kondolf and Micheli (1995).

There is no guarantee that access to historic coaster brook trout habitat will result in the re-establishment of the population in these areas. However, natural resource biologists and local sport fisherman who continually observe coaster brook trout populations in the vicinity of Kama

Creek can verify, through local experience and commitment to future management and monitoring, that both adult and juvenile fish will occupy these restored areas.

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